June 2012

Long Term Simulation of Residual Fly Ash Transport and Fate in the Watts Bar Reservoir System

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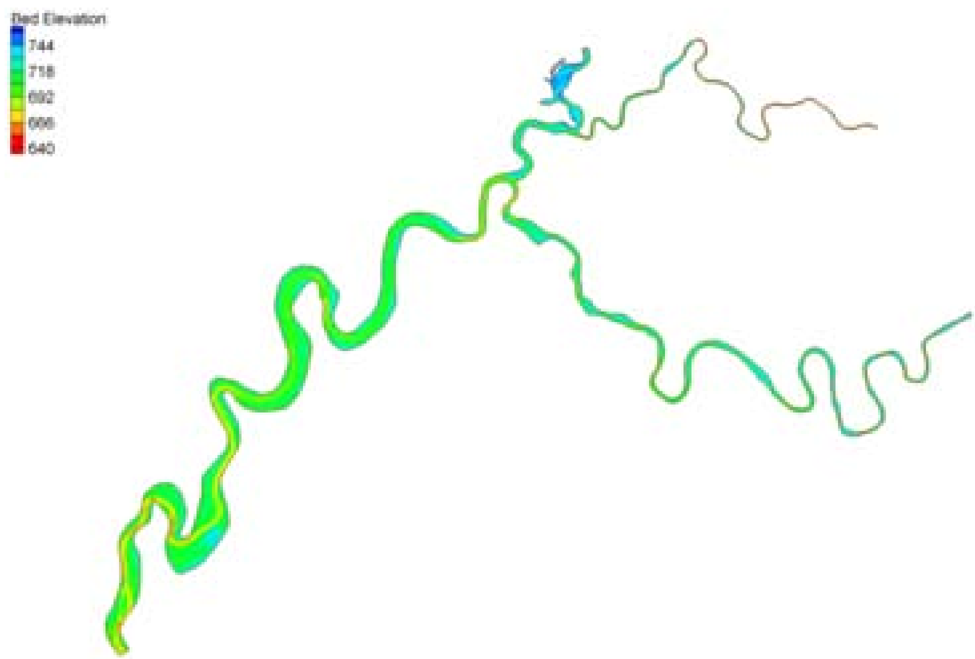

Final Report

Prepared for EPA Region 4, Atlanta Georgia

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE
Long Term Simulation of Residual Fly Ash Transport and Fate in the Watts Bar Reservoir System

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineering Research and Development Center,Coastal and Hydraulics Laboratory,Waterways Experimentation Station (ERDCWES),3909 Halls Ferry Road,Vicksburg,MS,39180

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
On December 22, 2008, an approximate 120 acre ash disposal cell at the TVA Kingston Fossil Plant failed, resulting in the release of an estimated 5.4 million cubic yards of coal fly ash to the Emory River and surrounding areas. The dredge cell failure was attributed to a geotechnical failure of the containment berms around the cell. The release extended over approximately 300 acres outside the ash storage area, with approximately 3 million cubic yards of fly ash deposited in the Emory River channel adjacent to the plant, as well as 1 to 2 miles upstream and downstream of the plant.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**48**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

INTRODUCTION

On December 22, 2008, an approximate 120 acre ash disposal cell at the TVA Kingston Fossil Plant failed, resulting in the release of an estimated 5.4 million cubic yards of coal fly ash to the Emory River and surrounding areas. The dredge cell failure was attributed to a geotechnical failure of the containment berms around the cell. The release extended over approximately 300 acres outside the ash storage area, with approximately 3 million cubic yards of fly ash deposited in the Emory River channel adjacent to the plant, as well as 1 to 2 miles upstream and downstream of the plant.

The Engineering Research and Development Center at Waterways Experiment Station (ERDCWES) performed two previous fly ash transport studies for the EPA utilizing a two dimensional sediment transport model developed at the ERDCWES called Adaptive Hydraulics (AdH). The initial study (Scott 2010) evaluated the fate and transport of ash from an Emory River storm event that occurred soon after the spill. In May 2009, a 70,000 cfs storm event occurred on the Emory River that transported a significant amount of ash from the spill area to downstream reaches of the Emory, Clinch, and Tennessee Rivers. The 2010 study provided guidance on the fate of the fly ash transported by the storm by grain size throughout the system.

In 2011, the EPA contracted with ERDCWES to investigate the feasibility of a Monitored Natural Recovery (MNR) approach as a remedial option for fly ash residuals in the system (Scott 2011). A two year model simulation was conducted utilizing the final results from the 2010 study. The final fly ash bed concentrations from the 2010 model simulation were used as the initial condition for the MNR simulation. Natural incoming sediments from the Emory, Clinch, and Tennessee Rivers were input into the model over a two year flow record. The study results indicated that the effectiveness of an MNR remedy increases with distance downstream from the site. The remedy would be most effective for the lower Watts Bar Reservoir (Tennessee River segment), with the least effective being the lowermost 1.5 mile reach of the Emory River just below the site. This finding is a direct function of the amount of sediment introduced into the reservoir system from the three rivers. Although the two year simulation provided a relatively short term evaluation of the impact of sediment supply on ash burial and dilution, it did not address the impact of large channel forming Emory River floods on natural sediment and fly ash residual redistribution over a longer period of time.

The effort described in this report details the results of a thirty year model simulation designed to evaluate how residual ash will erode, transport, and sort in the bed over an extended period of time and after a number of large storm events. Areas of high ash residual concentration were inserted into the model based on contour maps developed by the TVA. A thirty year record was simulated (1978 – 2008), with bed displacement and ash percentage computed for remaining sediment and ash deposits throughout the system after thirty years.

BACKGROUND AND BOUNDARY CONDITIONS

The Adaptive Hydraulics model mesh used in the 2011 study was modified to reflect new bathymetric surveys in the lower Emory River and residual ash deposits measured in the lower

Emory and Clinch River systems. Figure 1 depicts the location, along with ash depth and area of the ash residuals that were assumed in the AdH model. It was assumed that the ash composed 50 percent of the bed sediment in known ash deposit areas. Additionally, the upstream boundary of the mesh was extended approximately 1.6 miles upstream to ERM 5.7 (Figure 2).

Model inflow boundary conditions consisted of a thirty year discharge record from 1978 – 2008. As with the previous studies, flow boundaries were included for the Emory, Clinch, and Tennessee Rivers, along with a 30 year stage boundary at the Watts Bar Dam headwater. Mean daily flows were used for non-flood events, with peak flows used for the flood hydrographs. Fourteen significant storm events occurred over the thirty years including an eight year return storm event (108,000 cfs peak flow) and a thirty year storm event (170,000 cfs peak flow). The date these storm events occurred along with the peak flows is detailed in Table 1. The river inflows are found in Figures 3, 4, and 5.

For this simulation, six natural sediment grain sizes were utilized in the model. The fine sediment grain sizes consisted of clay, fine silt, and medium silt, with the coarse sizes consisting of fine, medium, and coarse sand. Because this simulation included larger storms, a sand transport rating curve was included based on the Emory River sand transport capacity. A hydrodynamic evaluation of transport capacity at the upstream boundary indicated that the minimum flow for which fine sand would transport is approximately 13,000 cfs, thus primarily fine sand entered the model for flows greater than 13,000 cfs. As with the previous studies, only clay and silt was discharged into the Clinch and Tennessee Rivers. The thirty year Emory River fine and coarse sediment concentration data are found in Figures 6 and 7, with natural bed sediment composition depicted in Figure 8. The residual fly ash was represented in the model by the mean ash grain size (0.24 mm).

Laboratory studies conducted at the ERDC indicate that pure ash has a critical shear stress for erosion of about 0.5 Pascals (0.01 lb/ft^2). A pure sample of cohesive Watts Bar sediment has a critical bed shear stress of about 2.0 – 2.5 Pascals (0.04 – 0.05 lb/ft^2). When mixed together in the Laboratory, the composite bed sample has a critical shear stress of about 1.5 Pa (0.03 lb/ft^2), which is less than cohesive sediment, but more than pure ash. This value of critical shear stress was used in the model calculation for all fine sediments, along with corresponding laboratory derived erosion rates. The bulk density for the fine sediment bed in the model was assumed to be 1600 kg/m^3.

The model was executed on the ERDC High Performance Computing system. The average run time to complete the thirty year simulation was 144 hours.

SIMULATION RESULTS

In general, the upstream reach of the Emory (ERM 4 – 5.7) is depositional for the low to mean flows. The energy required to transport sediment in the upper Emory River is minimized by the Watts Bar dam headwater elevation. The controlling water surface elevation influences flow in the Emory River up to Oakdale Tennessee. Thus the channel stores inflowing sediments until flows are high enough to erode and transport downstream. The following description of how the

system behaves is accompanied by a series of contour plots describing bed change. Note that the residual ash areas depicted in Figure 1 are outlined in black on the bed change plots.

Deposition and Erosion Trends

For the first six years of the simulation there were no significant flow events greater than 50,000 cfs. Figure 9 depicts bed change after six years for the Emory and Clinch Rivers. There is very little erosion with the exception of the small area just below the water intake on the right descending bank. The remainders of the Emory and Clinch river areas are depositional. Note that the majority of the inflowing sediments are depositing in the upper Emory River channel reach (20 inches or more). Generally, deposition depths of about 1 inch or less occur in the mid to lower Emory River reaches (ERM 0 – 2.5), with somewhat higher depths occurring in the Clinch River (1 – 3 inches) due primarily to sediment inflows from the Clinch.

After 12 years, the channel has been exposed to two flows exceeding 60,000 cfs (Figure 10). Note that erosion is occurring in constricted channel areas (red contours) with deposition occurring throughout the remainder of the areas. Sediment accumulation depths range from 1-2 inches in the Emory River side channel areas to 5 inches or more in the Clinch. Note that with the exception of the main channel scour areas, the residual ash areas remain depositional.

In year 13, the thirty year flood event (170,000 cfs) occurs (Figure 11). This event scours the upper channel, as well as portions of the channel adjacent to the site, the lower Emory River channel, and the Clinch River channel. The sand that was previously stored in the upper channel has now migrated downstream, with the bulk depositing from ERM 3.0 to 4.0 in the upper channel, and ERM 2.5 in the area adjacent to the original spill site. Both of these areas are the traditional sand depositional areas for the Emory River. This areas have sediment deposits up to 20 inches or more. The residual ash stored in the upper Emory River channel (A1 on Figure 1), as well as in the channel adjacent to the site (A2) has scoured and transported downstream. Additionally, the small area with highest residual ash depth just below the water intake channel has completely scoured (A3) as well as ash residual area (A5). The ash residual area on the left descending bank (A4) is depositional, with the Clinch River ash residual area exhibiting scour on the downstream section and deposition on the upstream section (A6). Depositional areas have deposit depths ranging from 5 – 15 inches.

After thirteen years, the channel was exposed to eleven flood events greater than 50,000 cfs, with an eight year return flood of 108,000 occurring in year eighteen. Figure 12 shows year thirty bed change. The channel characteristics are similar (scour and depositional areas) to the year thirteen results, with the depositional side channel areas having increased depths of 10 – 20 inches in some areas. Figures 13 and 14 show the thirty year deposition and erosion linear contours respectively.

Time series data are presented for selected areas (Figures 15 and 16). Figures 17 – 27 show the depth of deposits. The upper Emory River channel deposition history is shown in Figure 17. Note that the channel stores sediment until the large flood in year thirteen (up to 20 inches). The channel then scours, and re-deposits after the storm. At year eighteen the second large flood scours the channel, with deposition occurring up to thirty years. Figures 18 and 19 represent the sand deposition areas in the upper channel and dredging site respectively. At year thirteen, the

large flood event deposits approximately 17 and 10 inches of primarily coarse sediments in these areas, with deposition occurring up to year thirty. The remainder of the deposition areas in the lower Emory and Clinch Rivers show peak deposition of 10 – 16 inches (Figures 20 – 23). Deposition depths in lower Watts Bar (TRM 530 – 567) range from 2 to 5 inches (Figures 24 – 27).

Percentage of Residual Ash in Deposits

For the first twelve years, very little ash was mobilized, transported, mixed, and deposited. Only ash deposits in the main channel areas were affected (Figure 10). Therefore the area was almost entirely depositional, with clean sediment deposits overlying the residual ash, isolating the ash from the water column. After the large flood in year thirteen, much of the residual ash was scoured from the main channel as well as some of the side channel deposits. The bulk of the residual ash was transported downstream and out of the lower Emory and Clinch rivers, however, ash and natural sediment mixtures did deposit in side channel areas of the Emory and Clinch Rivers.

Figures 28 – 31 show the percent residual ash in the deposits that occurred after 14 and 30 years of flows for both the lower Emory and Clinch river channels, and the lower Watts Bar area. The percent of ash residual in the deposits after fourteen years ranged from 5 – 15 percent for the Emory and Clinch rivers, and about 10 – 20 percent in lower Watts Bar Reservoir. After thirty years, the percent of residual ash drops due to continuous deposition of clean sediments, to approximately 3 – 8 percent in the Emory and Clinch river deposits and 5 – 10 percent in lower Watts Bar Reservoir.

Time series plots of the residual ash percentage for selected points in are found in Figures 32 – 37. The point locations are detailed on Figures 15 and 16. The point in the upstream channel experiences a short term spike in ash after the thirteen year storm. The points in lower Watts Bar Reservoir (Figures 34 – 37) show that the bulk of the residual ash transported to the lower reservoir after the year thirteen flood event.

DISCUSSION

Modeling results indicate that the Watts Bar Reservoir river system is highly dependent on flood flows for sediment delivery to downstream areas. Because of the far reaching back water effects of the Watts Bar headwater elevation, the upper reaches of the Emory River are depositional for over 90 percent of the yearly flows. Therefore, deposition rates are highest in the upper channel (1 – 1.5 inches per year) during average flow periods without significant storms. The depositional areas in the lower Emory and Clinch Rivers average about 0.1 – 0.25 inches per year in the absence of flood flows significant enough to mobilize bed sediments.

There is uncertainty in the model results presented in this paper. The inflowing sediment boundary conditions were estimated based on relatively old bed sediment surveys in Watts Bar reservoir. In addition, the erodible depth assumed in the model for the Emory and Clinch rivers was estimated. Maximum allowable channel scour depths were assumed because there are no vertical profile data on sediment depth to bedrock or other non-erodible (armored) layers.

Although a number of assumptions with relatively high uncertainty were made during this study, the relative model results are a good indicator of the sedimentation dynamics of Watts Bar Reservoir. The system is depositional the majority of the time, with large, flashy storm events scouring sediments off the channel bed and delivering them downstream to side channel depositional areas and the lower reaches of the reservoir (TRM 530 – 567). The ash residuals that are mobilized into the water column will mix with the relatively high natural sediment concentrations and transport downstream where they will ultimately deposit in mixed layers. The percent of ash in the deposits will trend down as successive flood events pass through the reservoir system. The model indicates that the residual ash percentage will drop below 5 - 10 percent for much of the depositional areas, which represents a dilution ratio of approximately 9 parts sediment to 1 part ash (a reduction from 50 percent ash to 5 percent ash in deposits).

CONCLUSIONS

A number of conclusions can be inferred from the modeling study:

- Average to moderately high Emory River flows are inefficient for delivering sediment load to the lower reaches of the Emory and Clinch rivers. The relatively low energy in the river system due to backwater effects of Watts Bar dam results in high deposition rates in the upper Emory River above the spill site for the majority of the flows.
- Although the model results indicate low deposition rates adjacent to and downstream of the spill area, any residual ash will be covered and isolated from the water column over time for low to moderately high Emory River flows.
- Model results indicate that flood events greater than the ten year return flood will scour residual ash located within channel high flow areas and re-deposit the ash in either low energy side channel areas, or transport to the lower Watts Bar Reservoir.
- Deposition rates in the Emory and Clinch river average about 0.5 inches per year over the thirty year simulation
- Sand deposition was greatest in the upper Emory River and adjacent to the spill site with total deposit depths of 60 and 20 inches respectively over the 30 year simulation
- Model results indicate that the percentage of ash in sediment deposits will gradually decrease with mixing and re-deposition throughout the river system. The percentage of residual ash in depositional areas ranged from 5 – 10 percent.

REFERENCES

Scott, S.H., "Simulation of Coal Fly Ash Erosion, Transport,and Fate From the Emory River at TVA Kingston", ERDCWES Unpublished Technical Report, June 2010.

Scott, S.H., "Sediment Transport Simulations to Support the Monitored Natural Recovery Process for Watts Bar Reservoir", ERDCWES Unpublished Technical Report, October 2011.

Tables and Figures

Table 1. Emory River flood events occurring from 1978 - 2008

Date	**Peak Flood Flow**	**Return Flood Period - year**
April 1984	60,377	2.5
January 1988	60,000	2.5
December 1990	170,000	30
February 1991	60,400	2.5
December 1991	70,300	3.0
February 1994	61,900	2.5
March 1994	66,600	3.0
December 1996	108,000	8.0
January 2002	75,200	3.5
March 2002	62,800	2.5
February 2003	62,600	2.5
May 2003	57,200	2.0
February 2004	63,700	2.5
September 2004	80,700	5.0

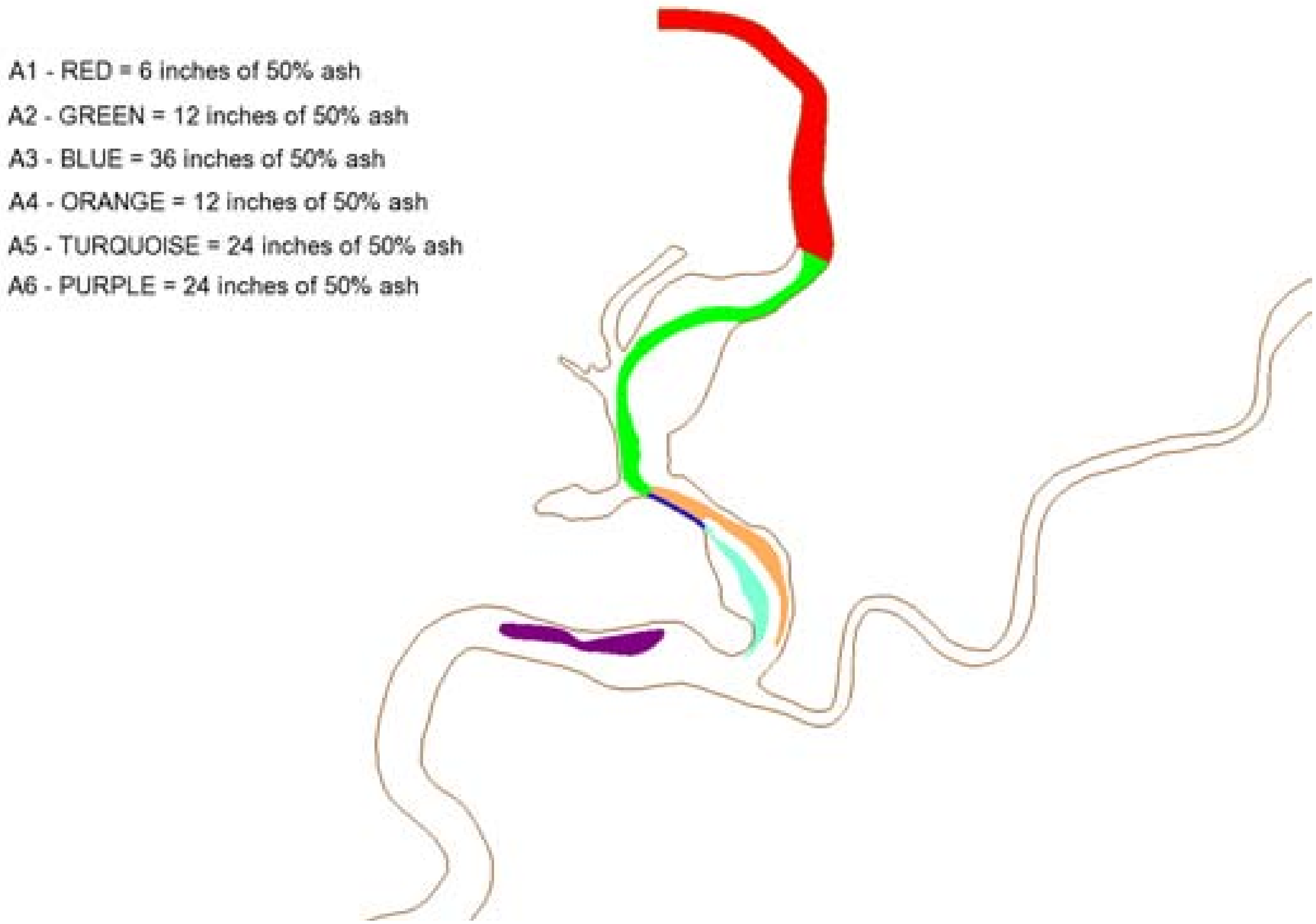

Figure 1. Location and depth of assumed ash deposits for the 30 year simulation

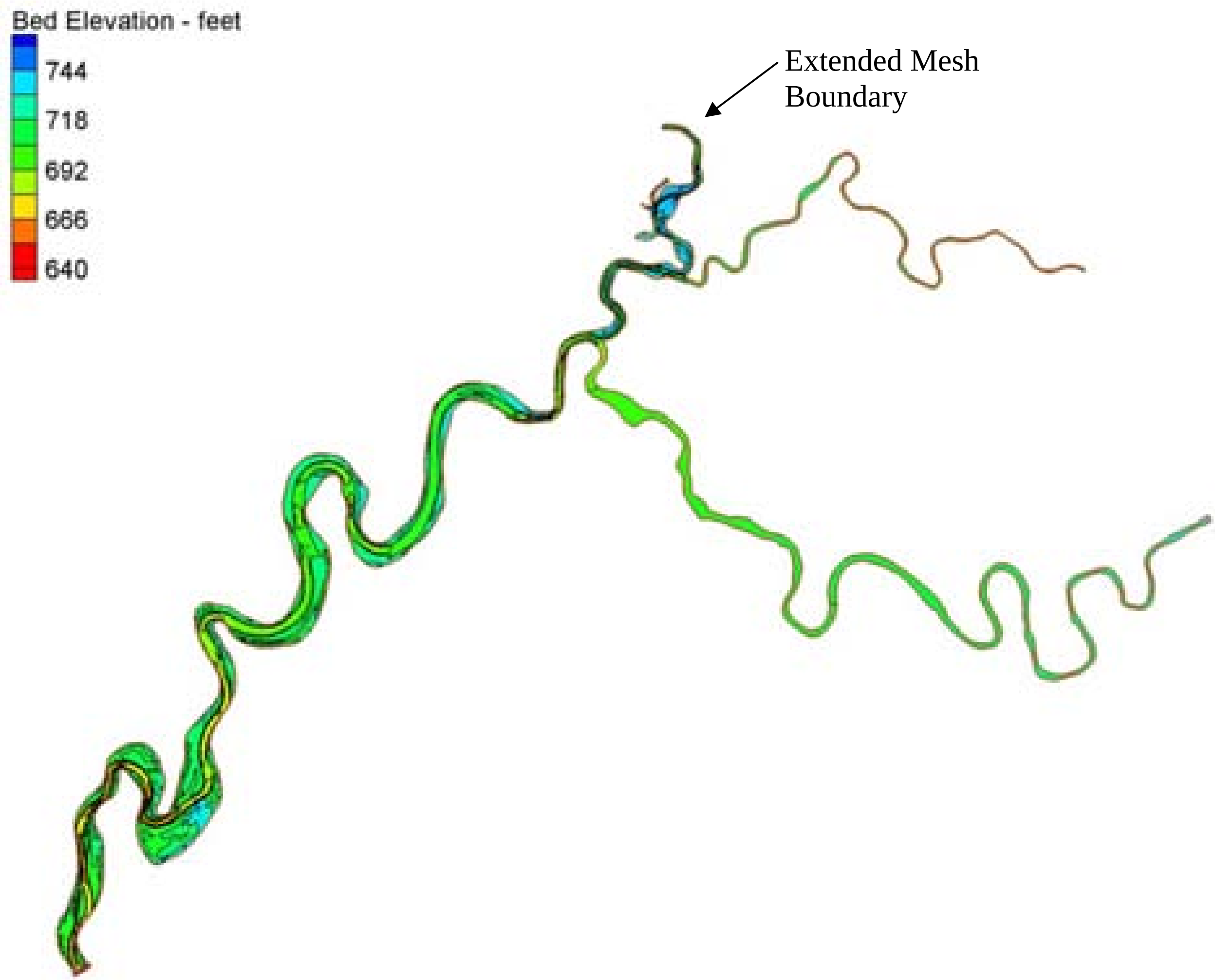

Figure 2. AdH model mesh used for the thirty year transport simulation

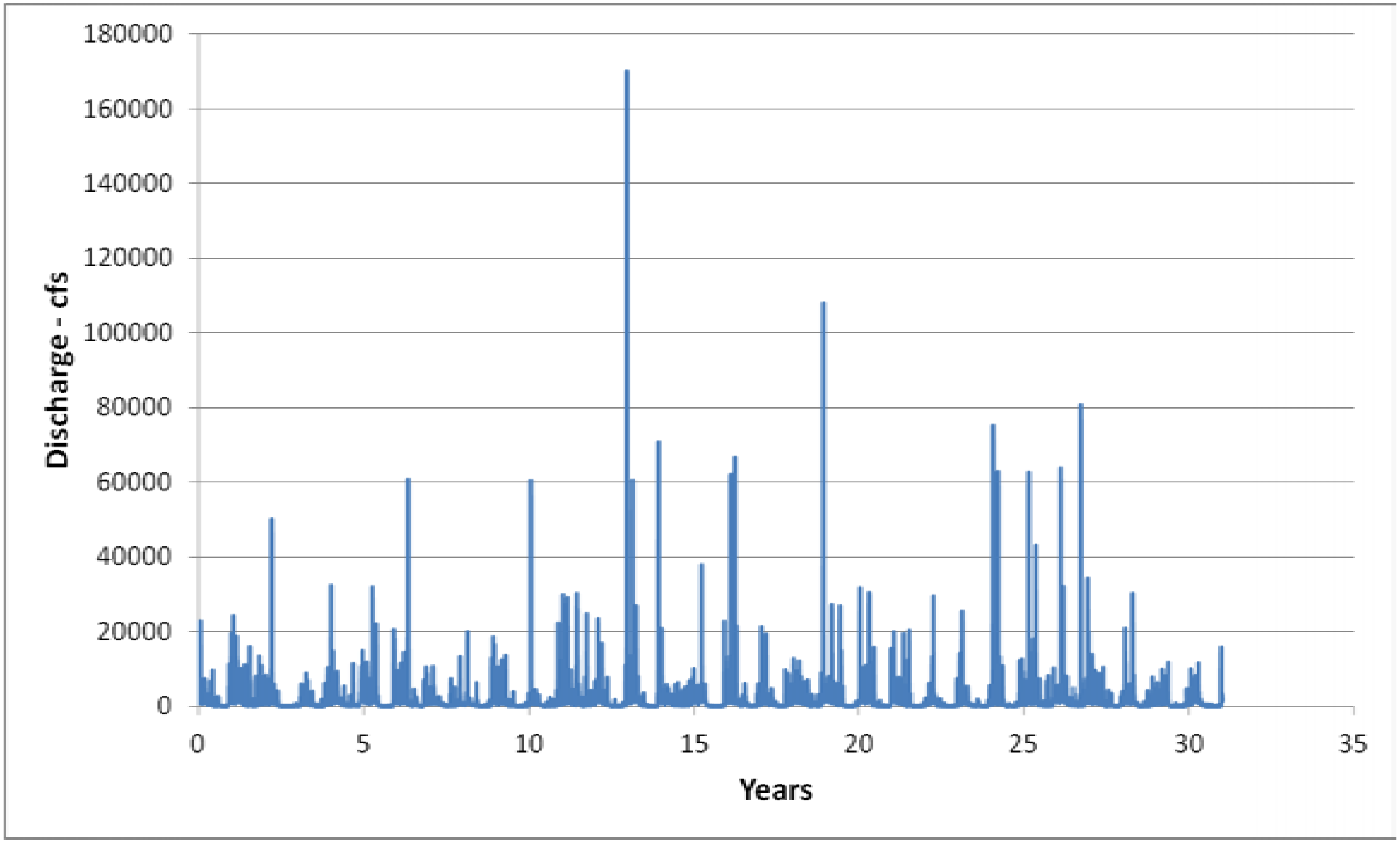

Figure 3. Thirty year discharge record for the Emory River

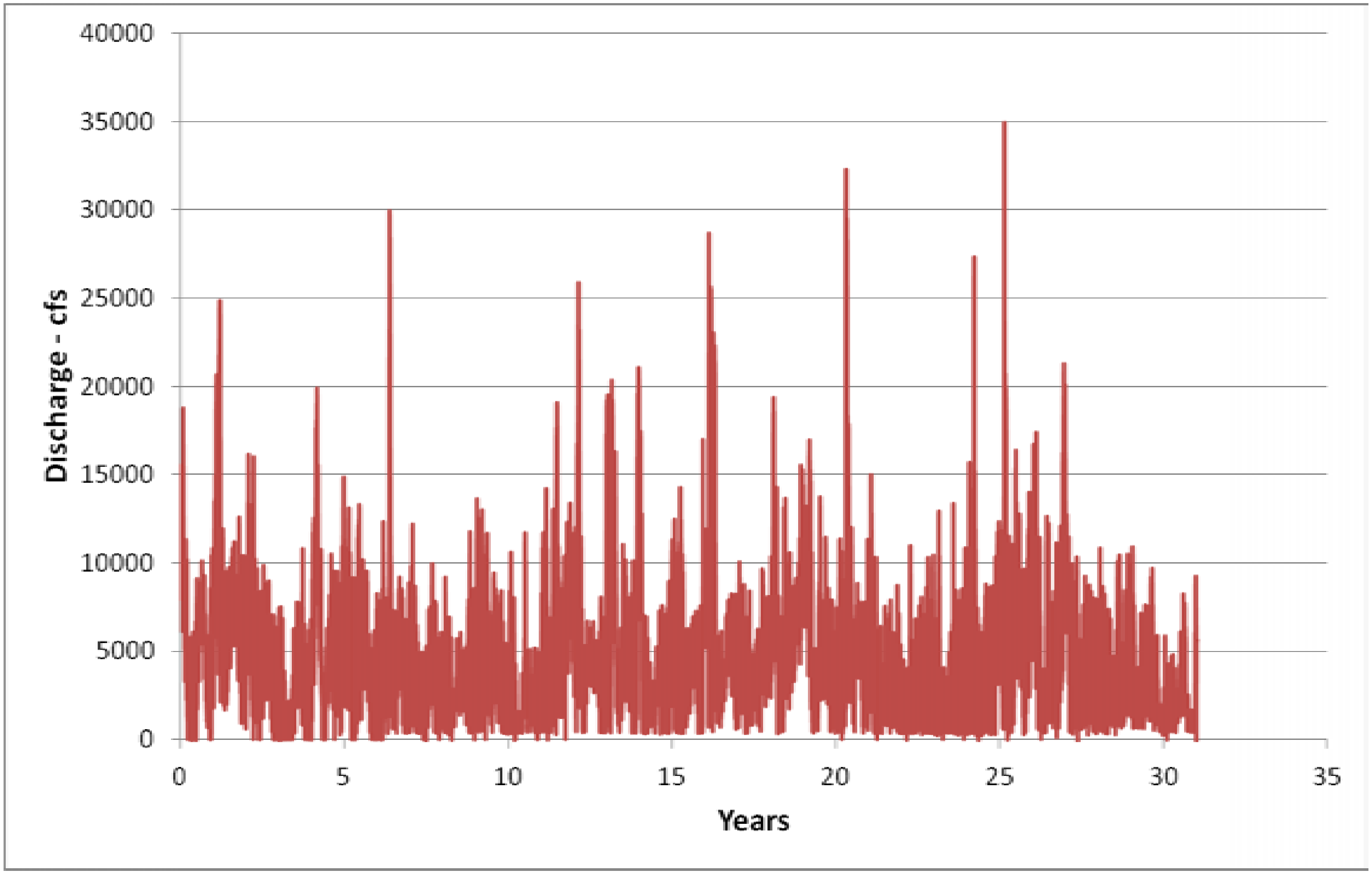

Figure 4. Thirty year discharge record for the Clinch River

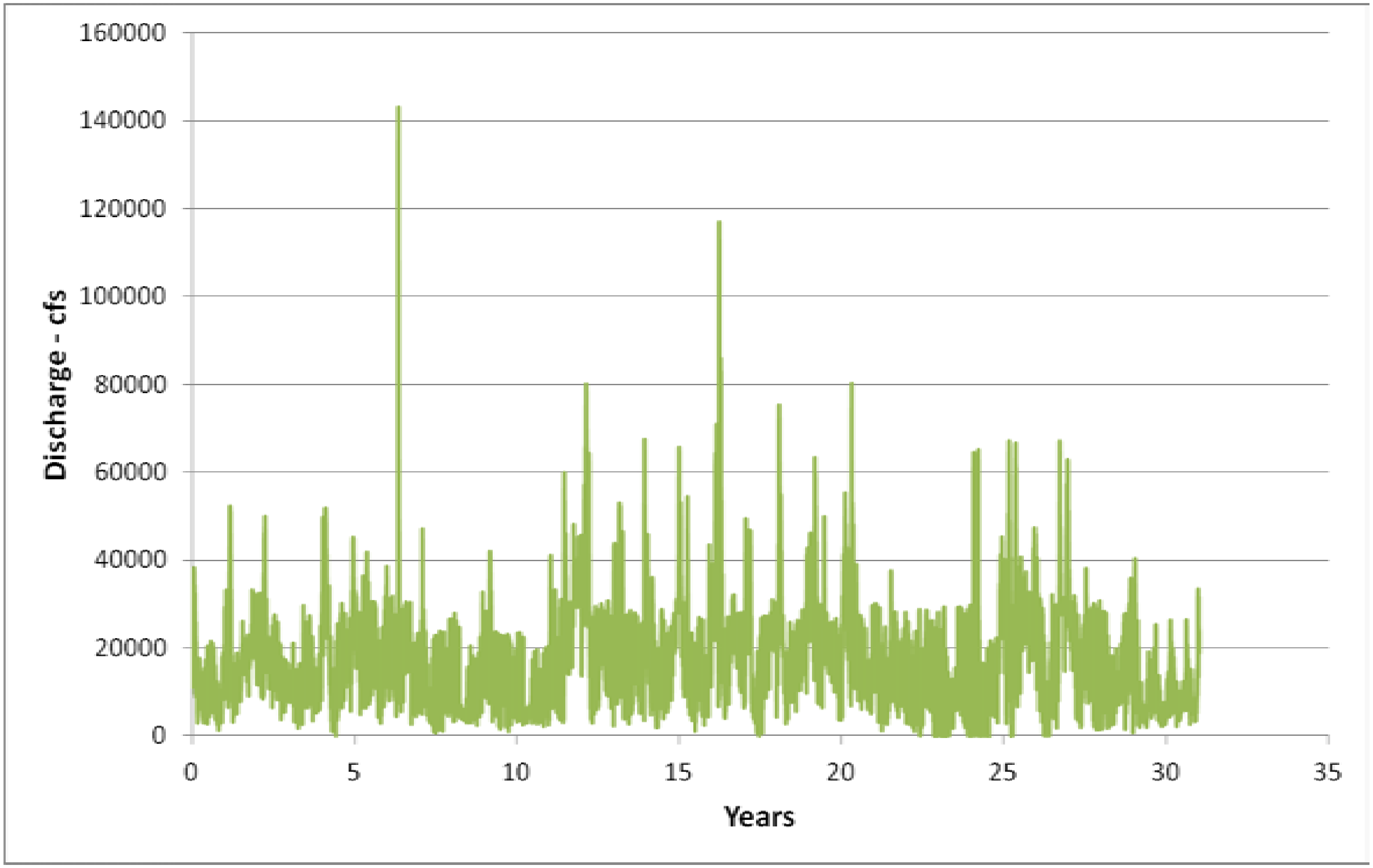

Figure 5. Thirty year discharge record for the Tennessee River

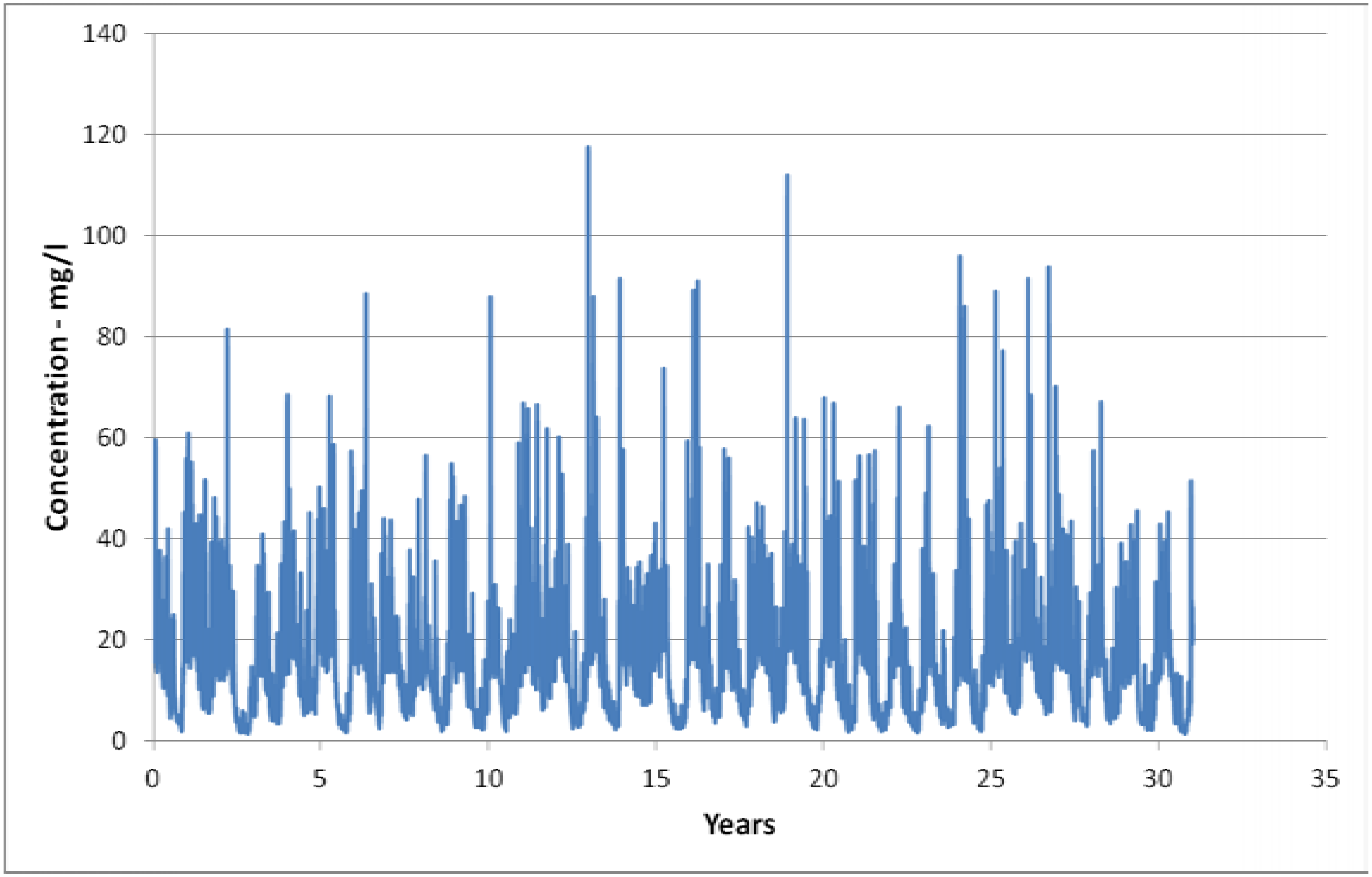

Figure 6. Thirty year suspended fine sediment concentration record for the Emory River

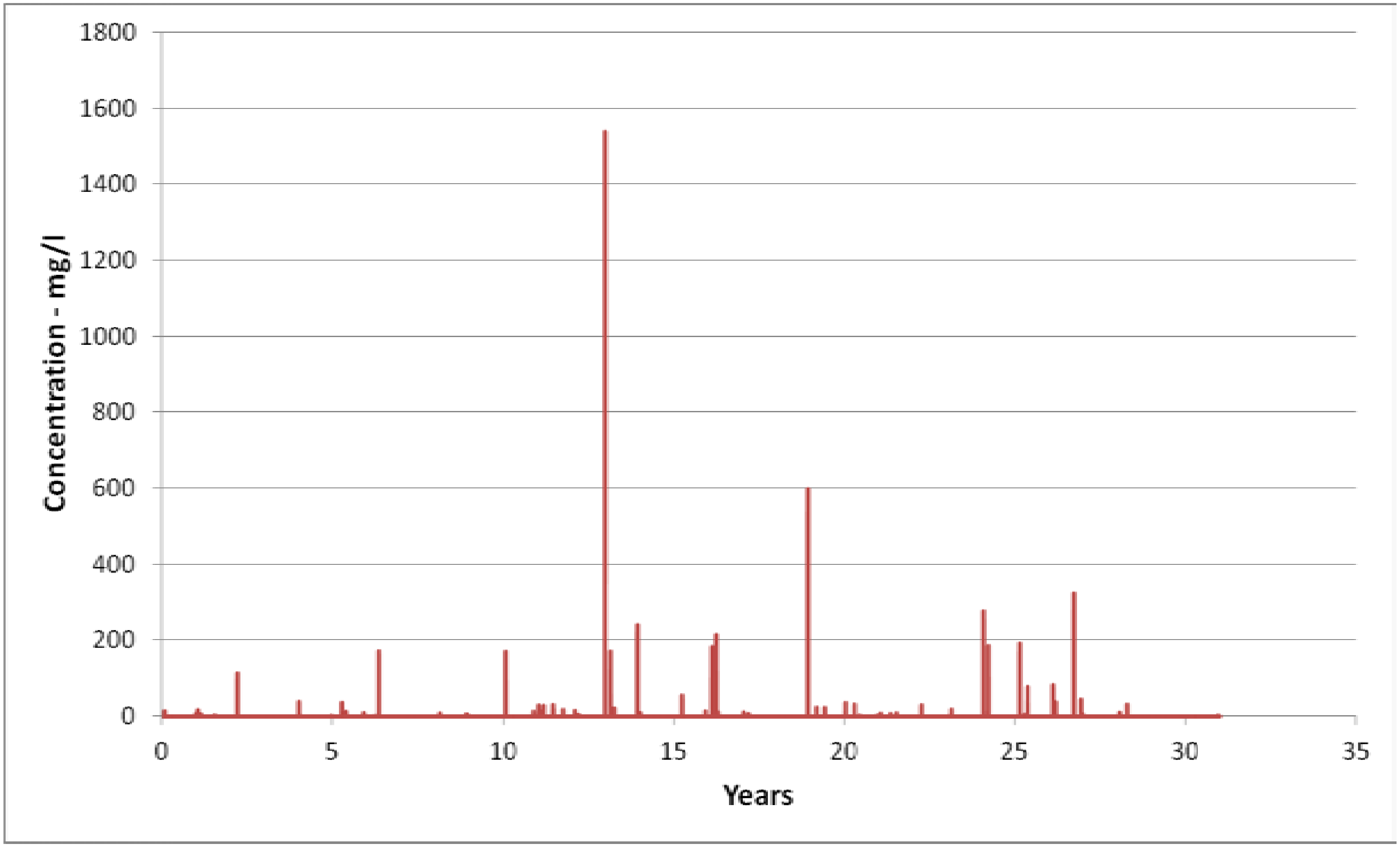

Figure 7. Thirty year sand suspended sediment concentration record for the Emory River

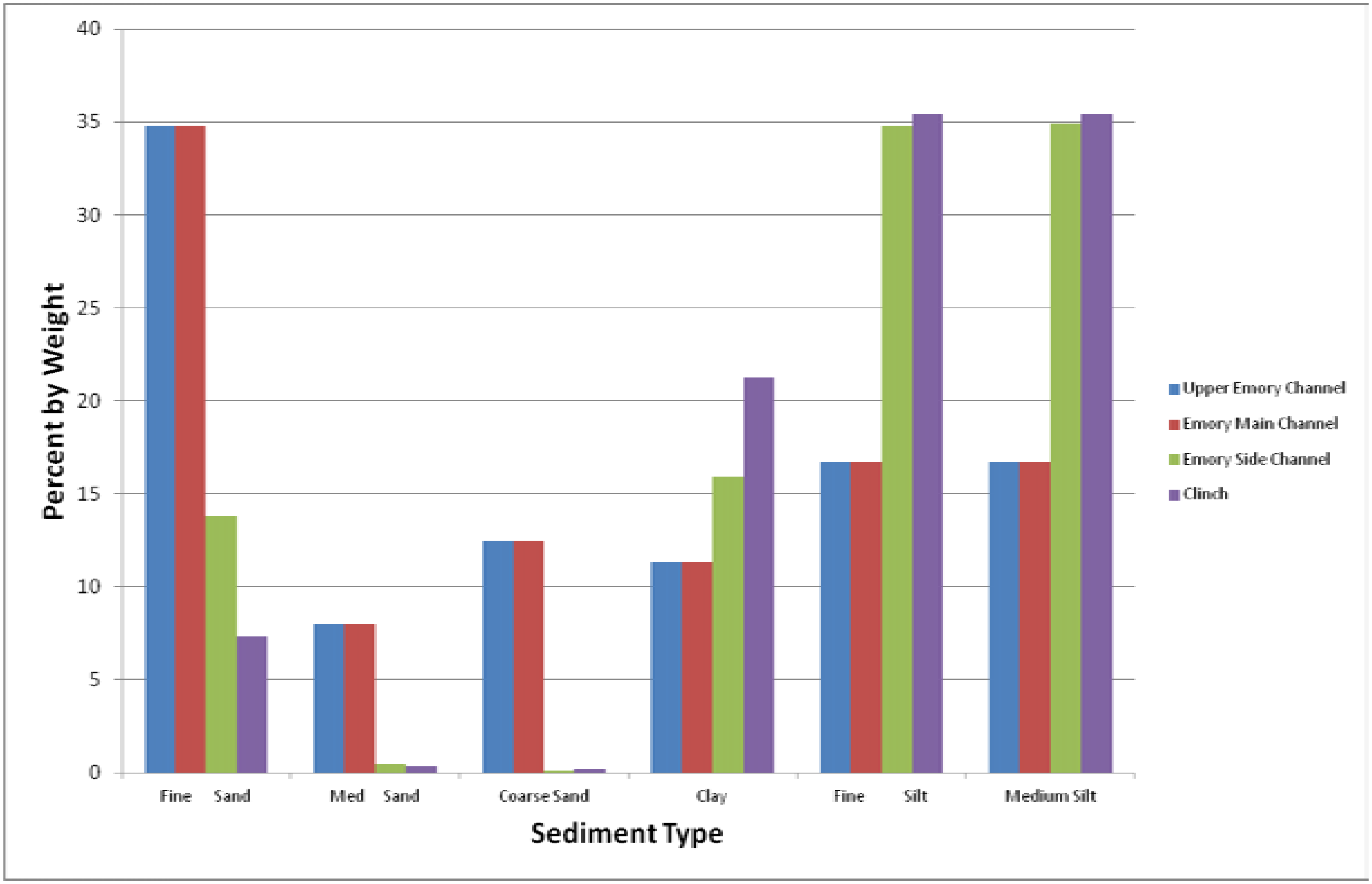

Figure 8. Bed sediment composition for the Emory and Clinch Rivers

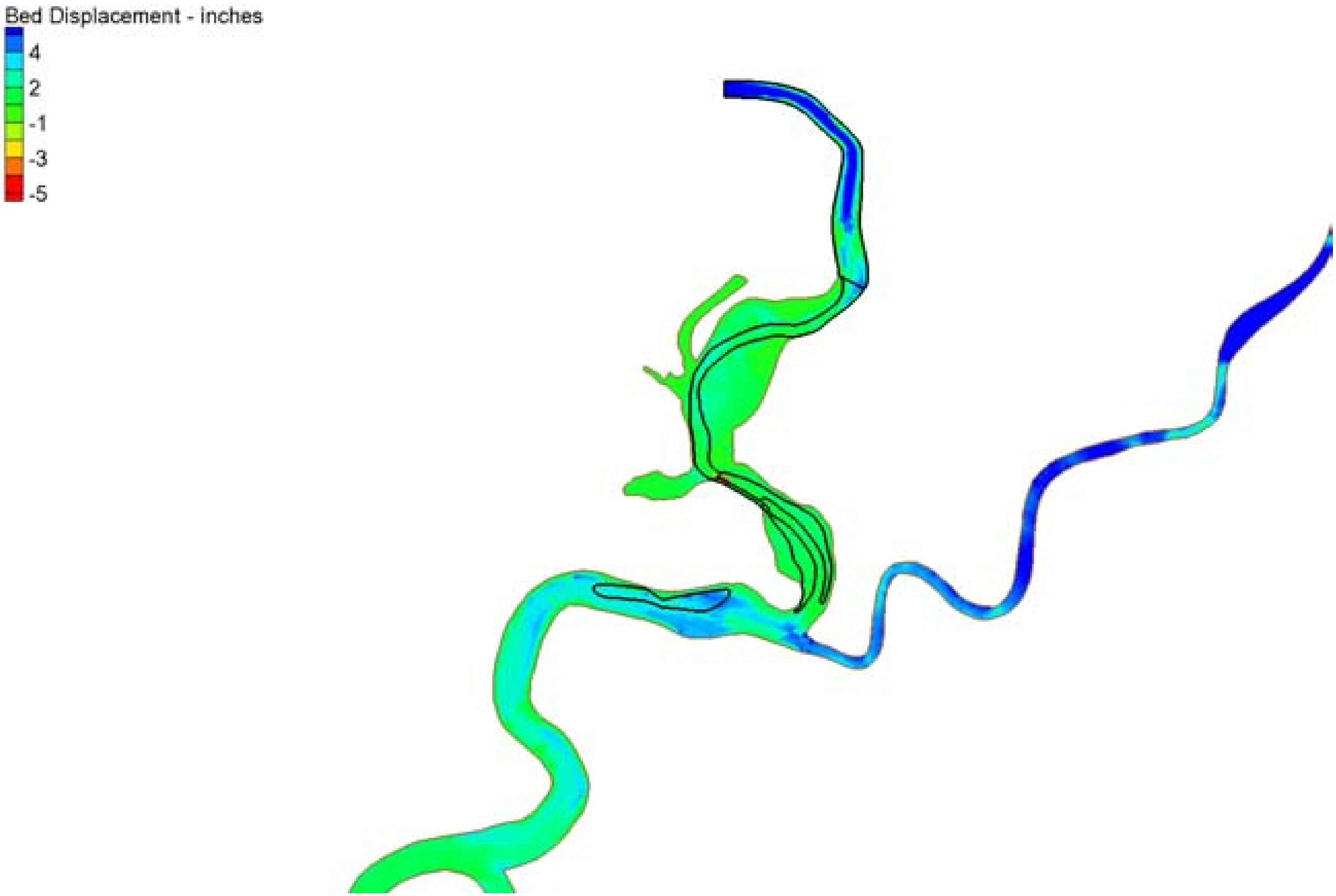

Figure 9. Bed change after six years

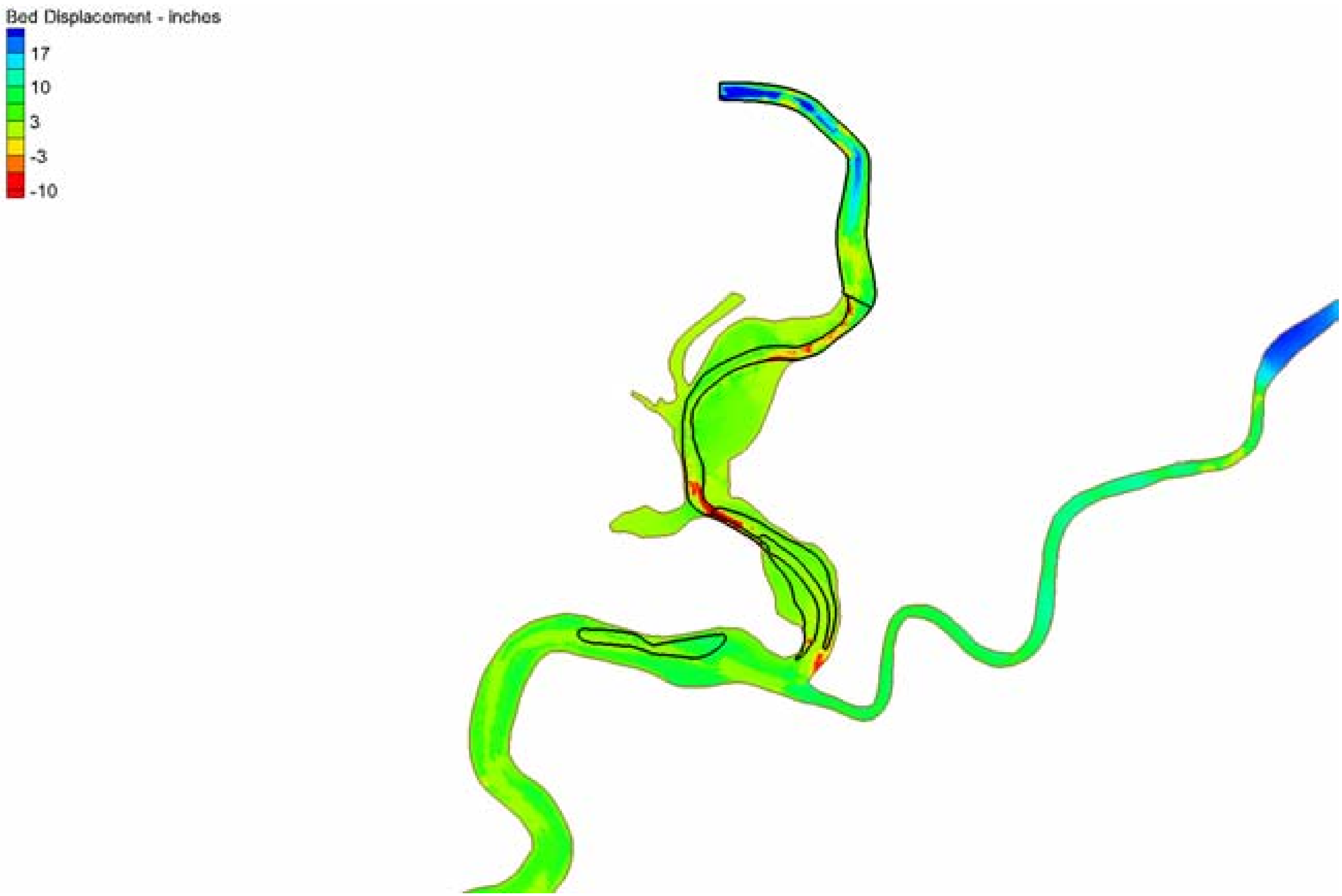

Figure 10. Bed change after twelve years

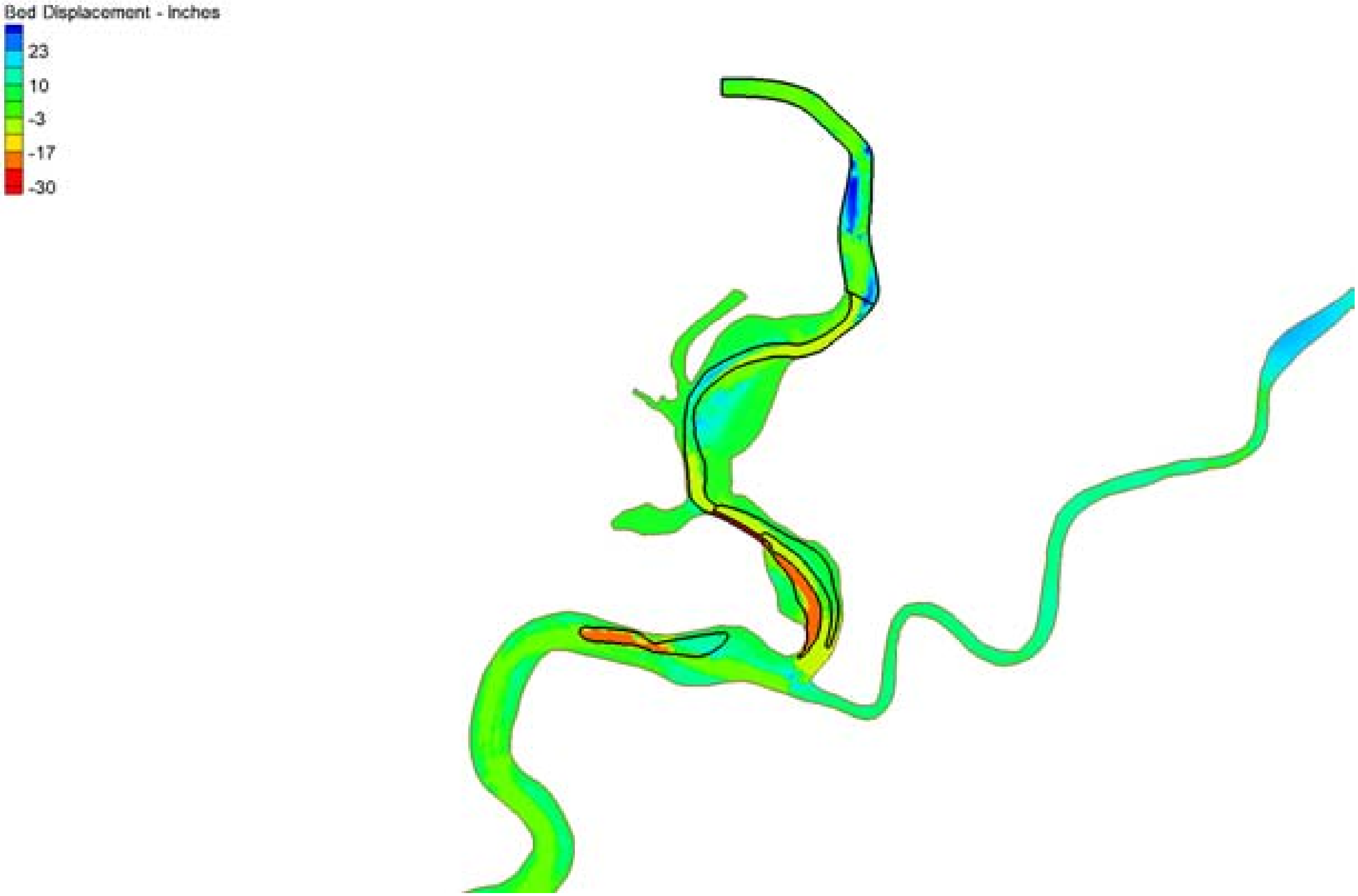

Figure 11. Bed change after thirteen years

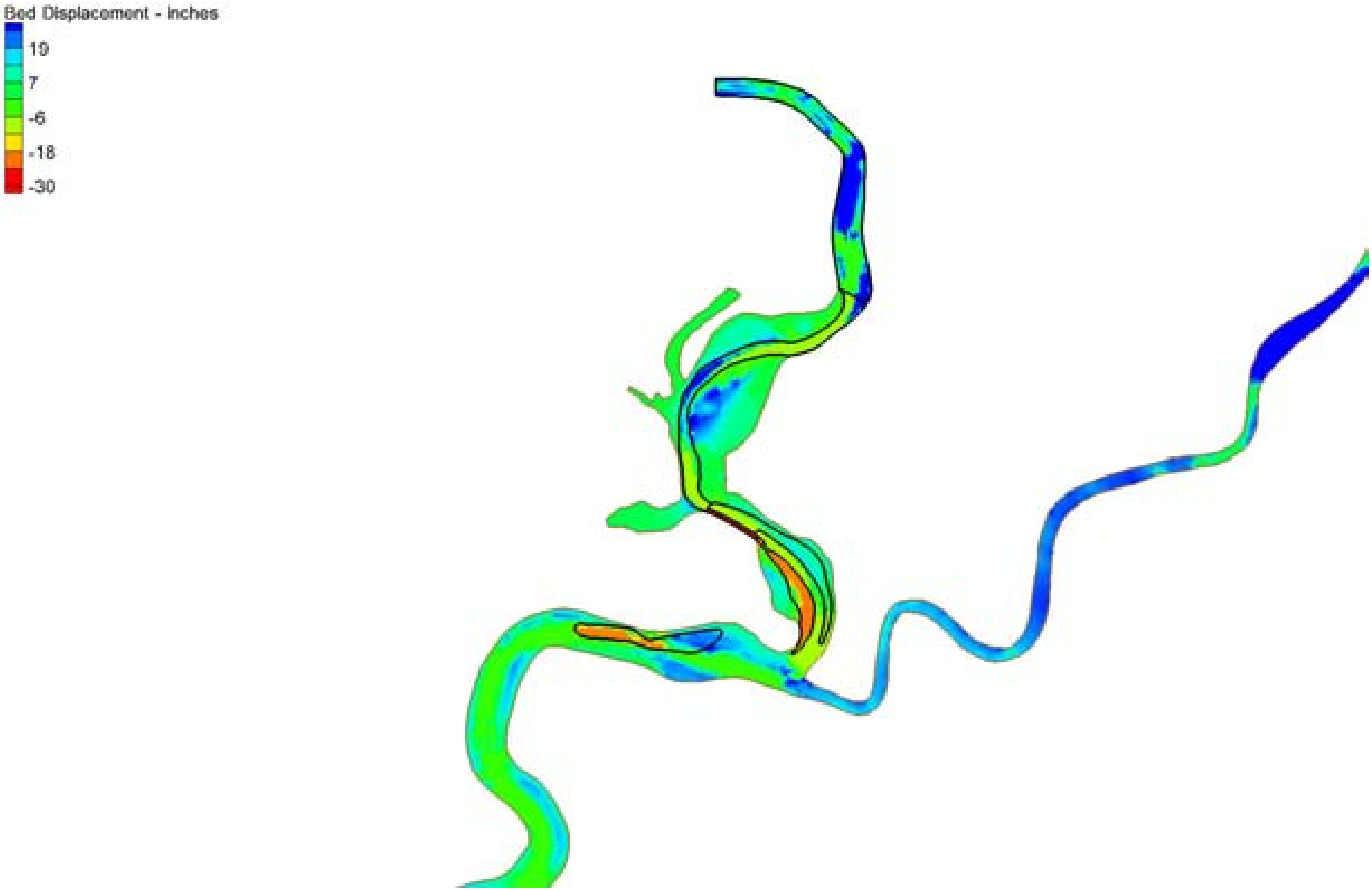

Figure 12. Bed change after thirty years

Figure 13. Sediment deposition linear contours after thirty years

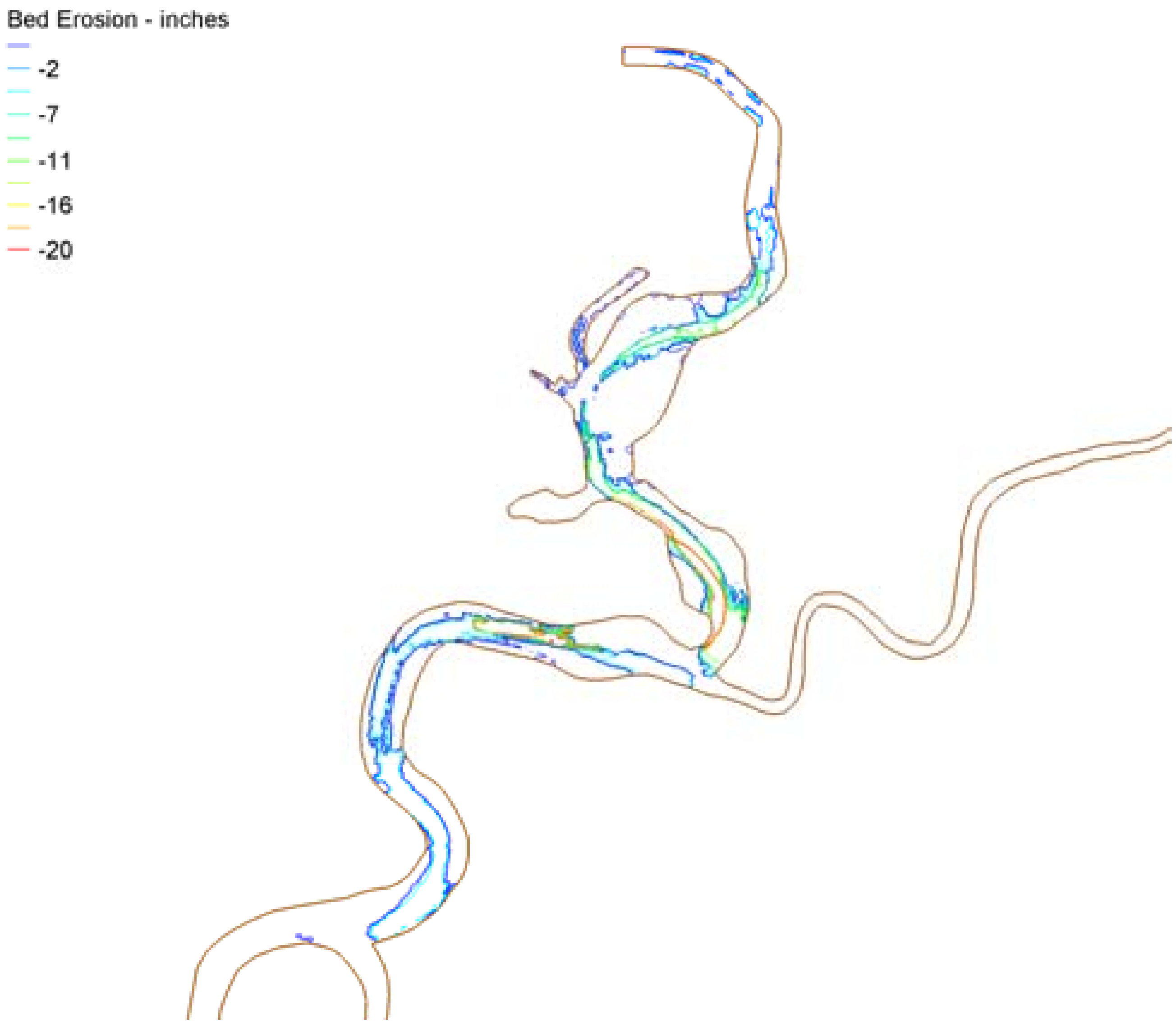

Figure 14. Sediment erosion linear contours after thirty years

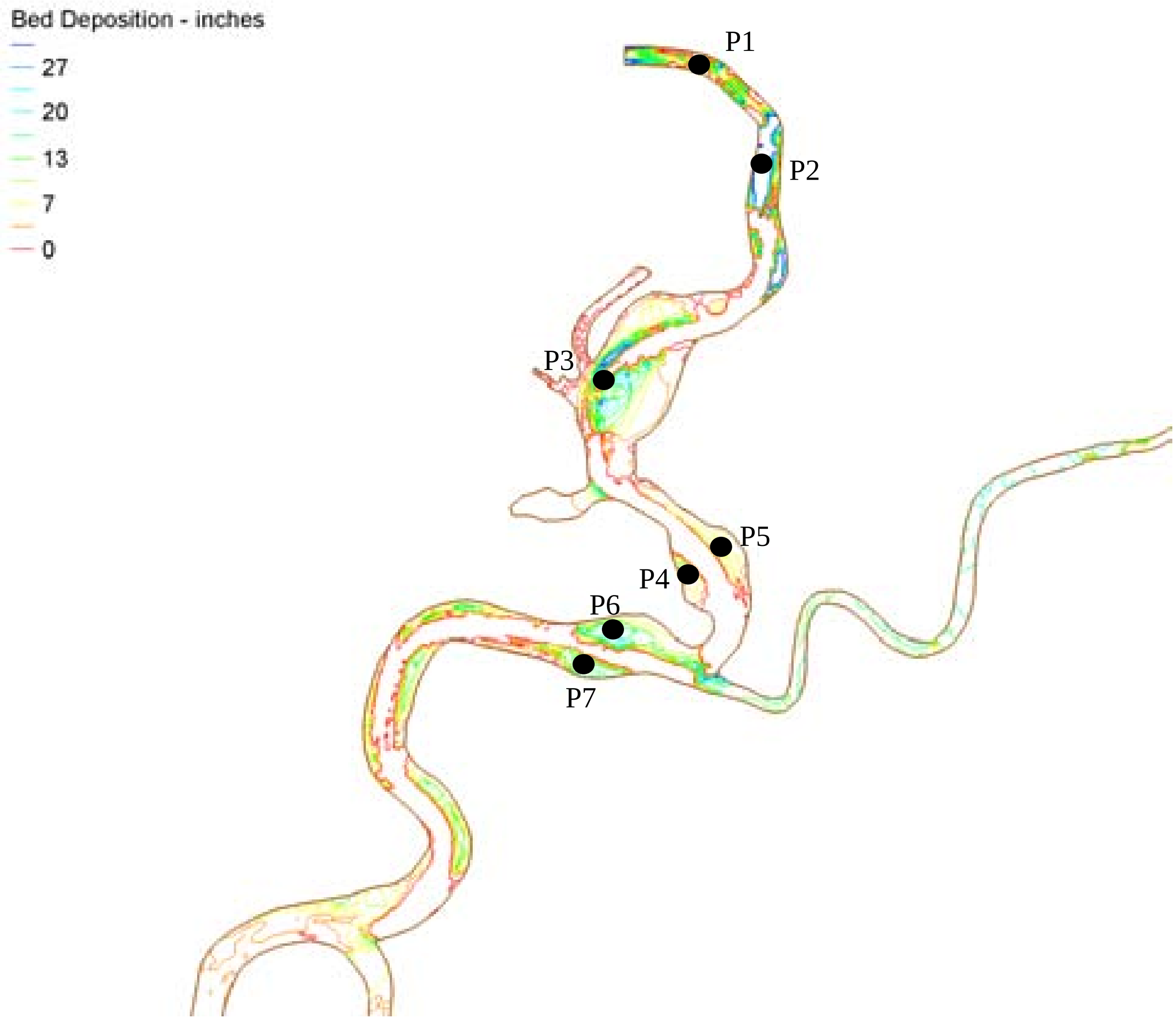

Figure 15. Location points for time series data on bed change

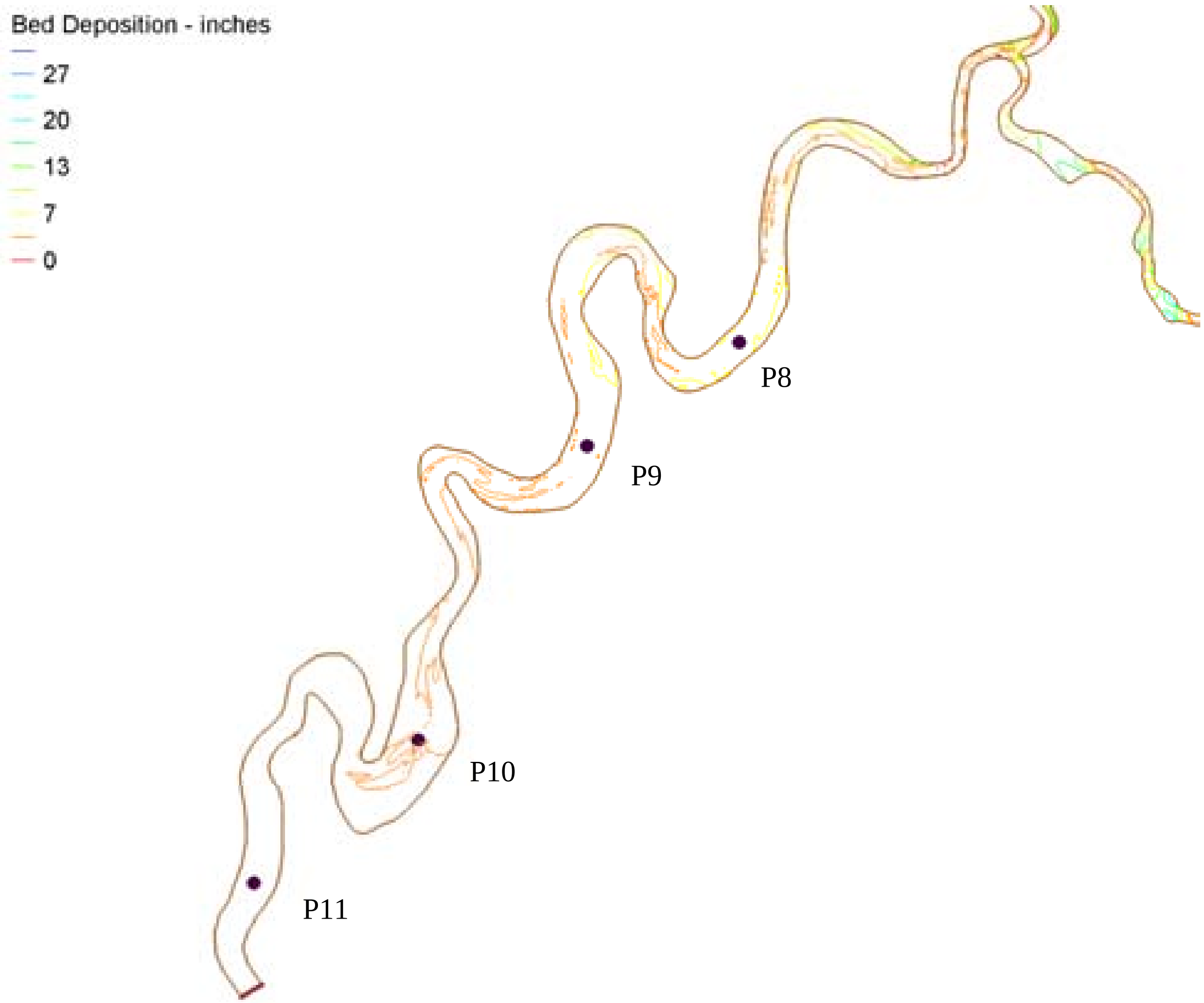

Figure 16. Location points for time series data on bed change – lower Watts Bar Reservoir

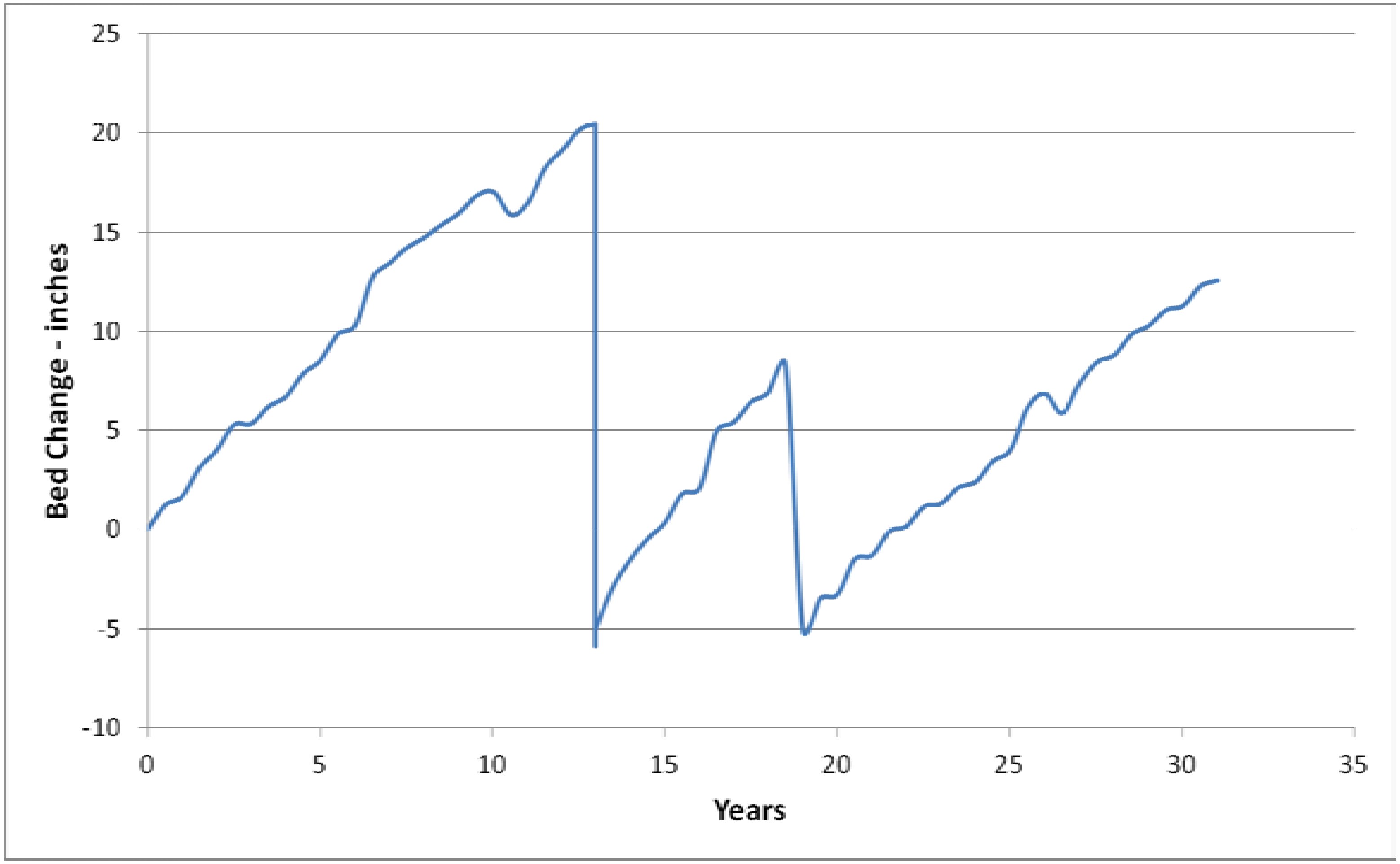

Figure 17. Bed change over the thirty year record for P1

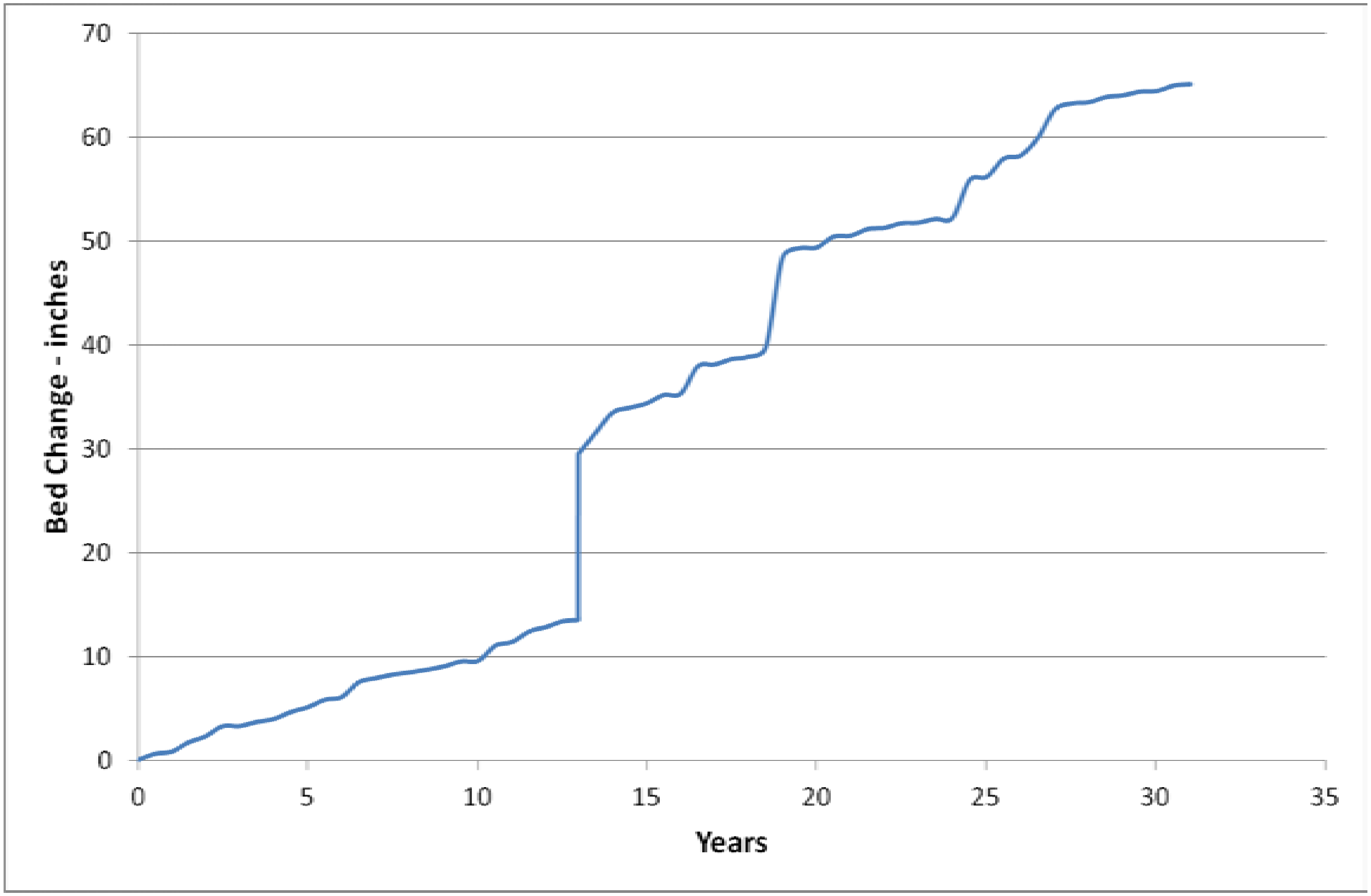

Figure 18. Bed change over the thirty year record for P2

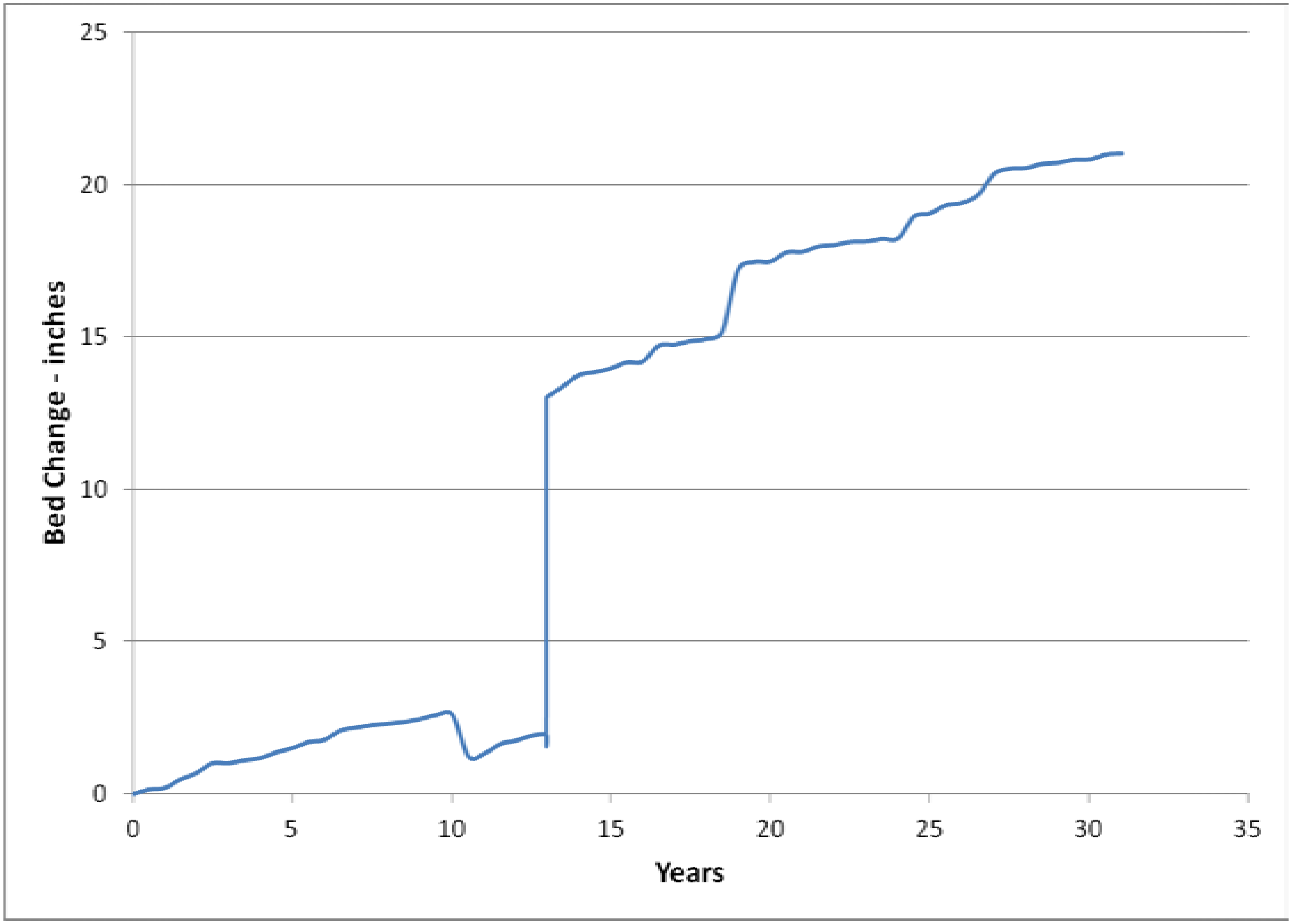

Figure 19. Bed change over the thirty year record for P3

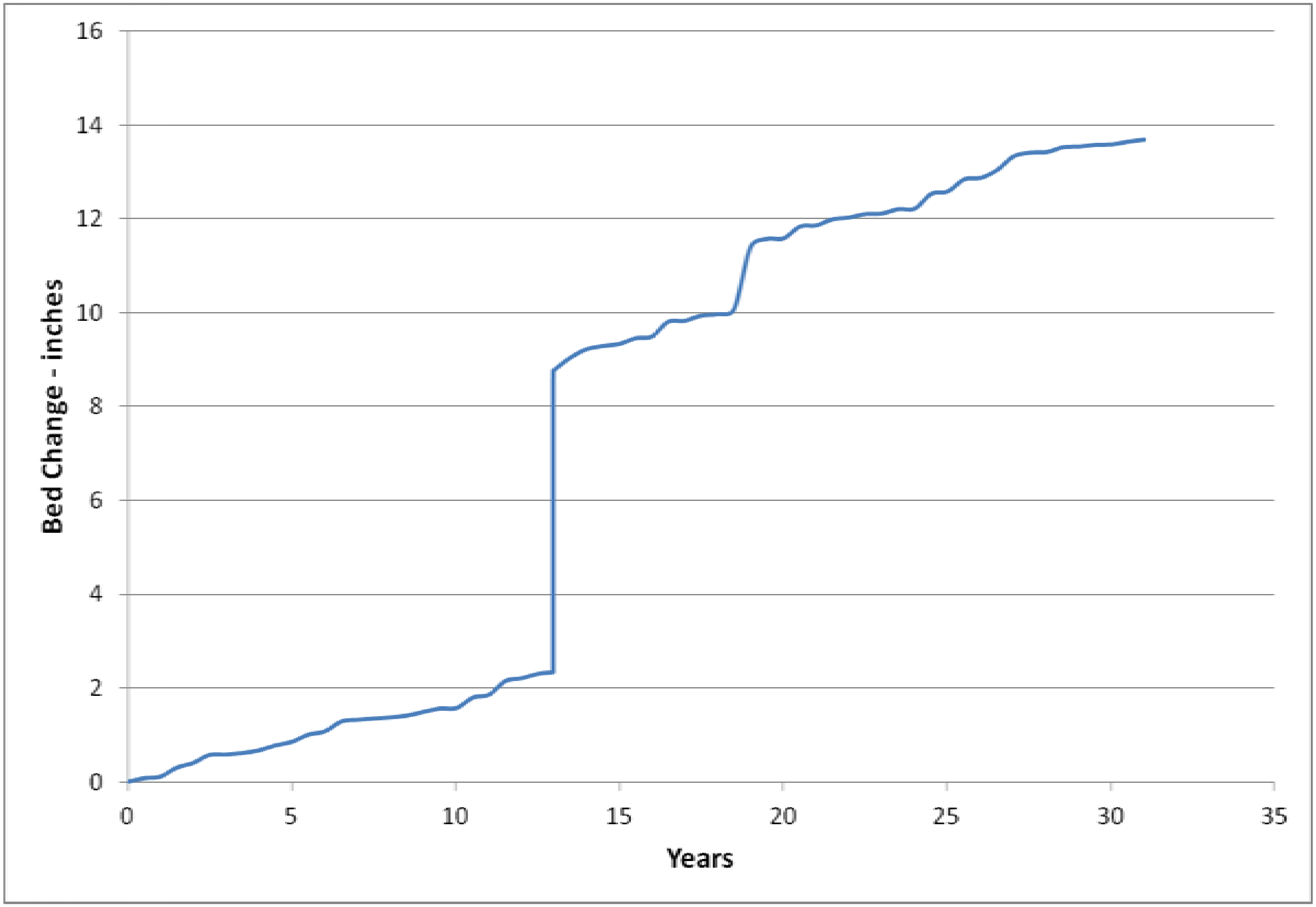

Figure 20. Bed change over the thirty year record for P4

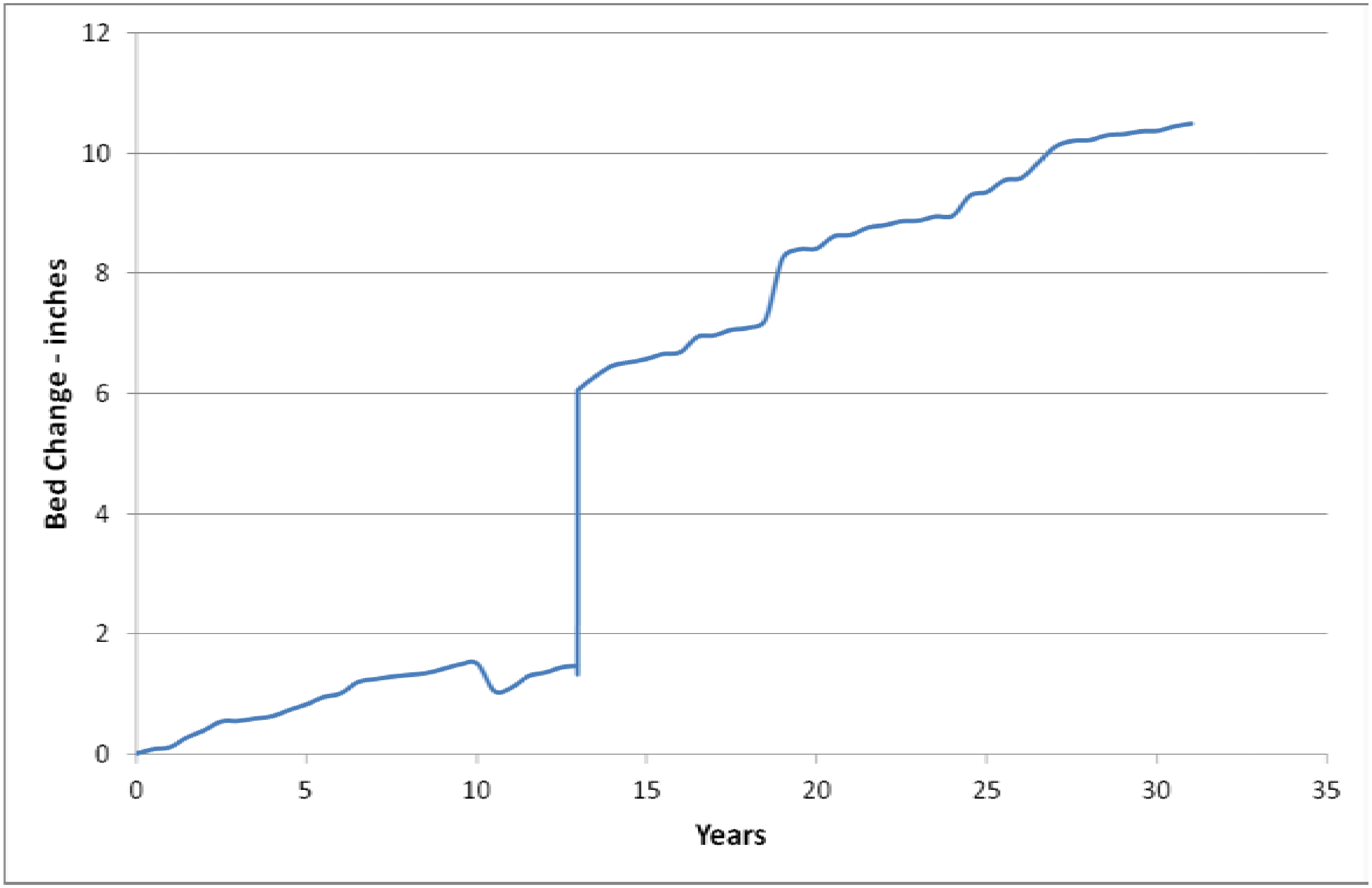

Figure 21. Bed change over the thirty year record for P5

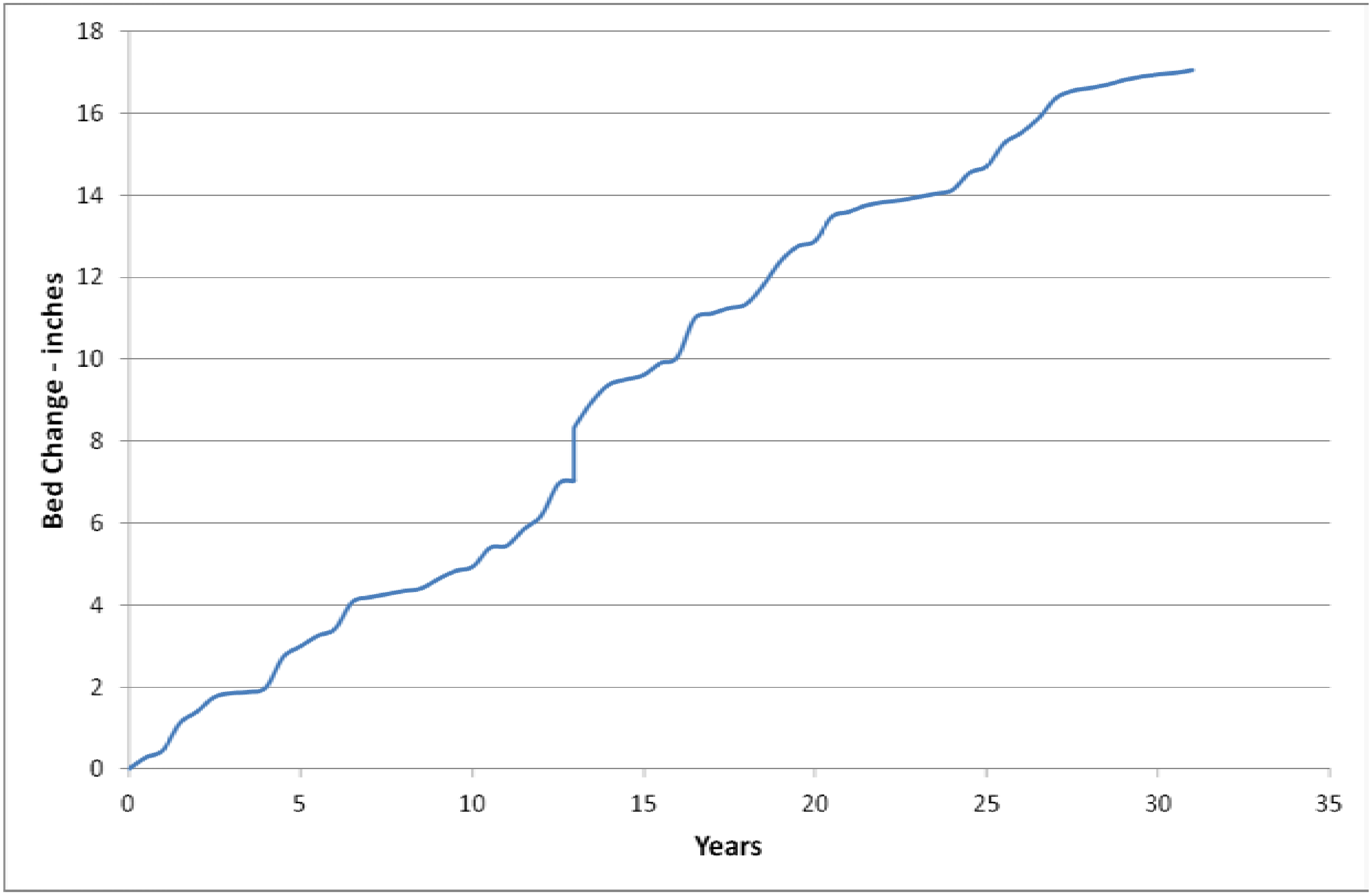

Figure 22. Bed change over the thirty year record for P6

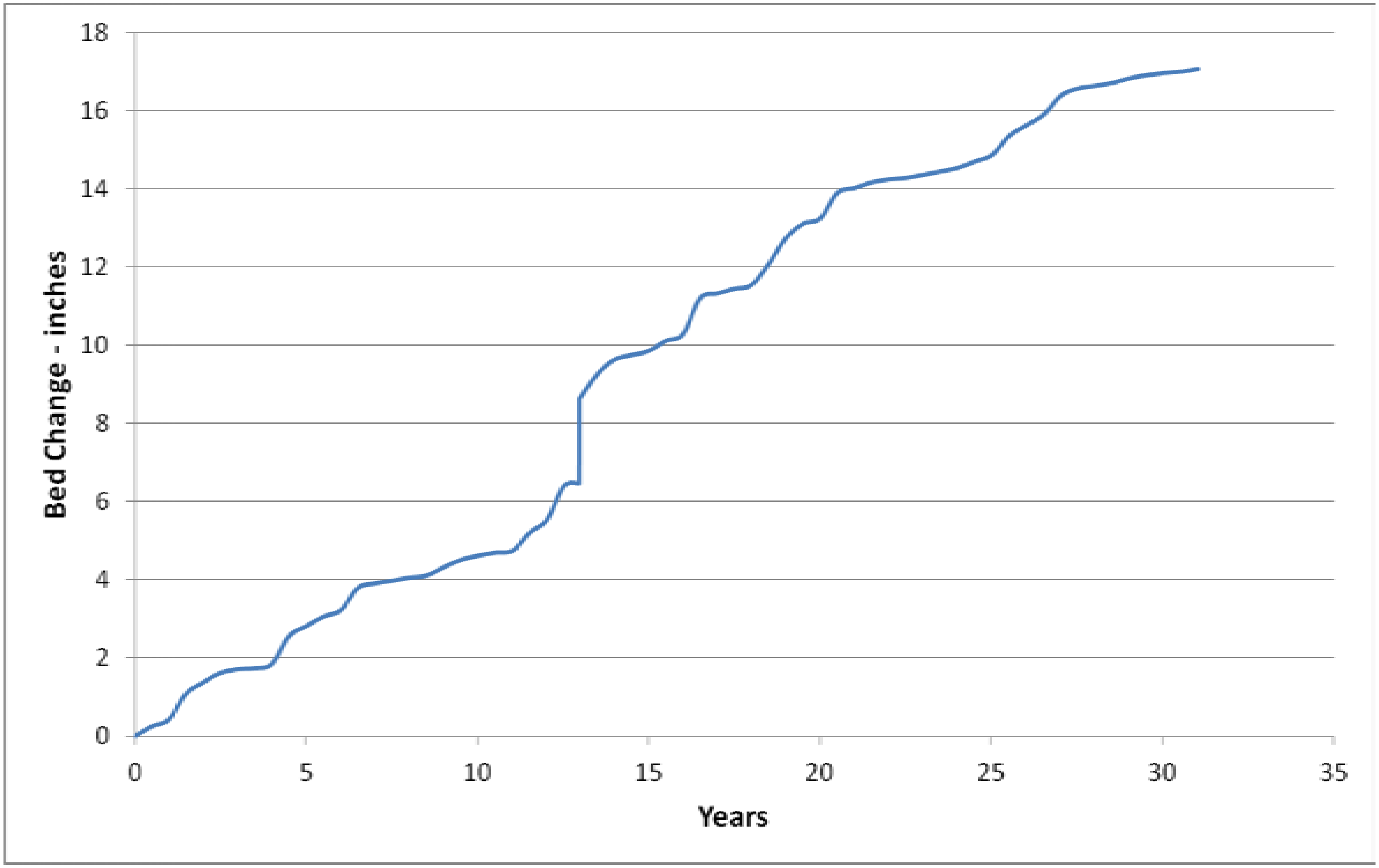

Figure 23. Bed change over the thirty year record for P7

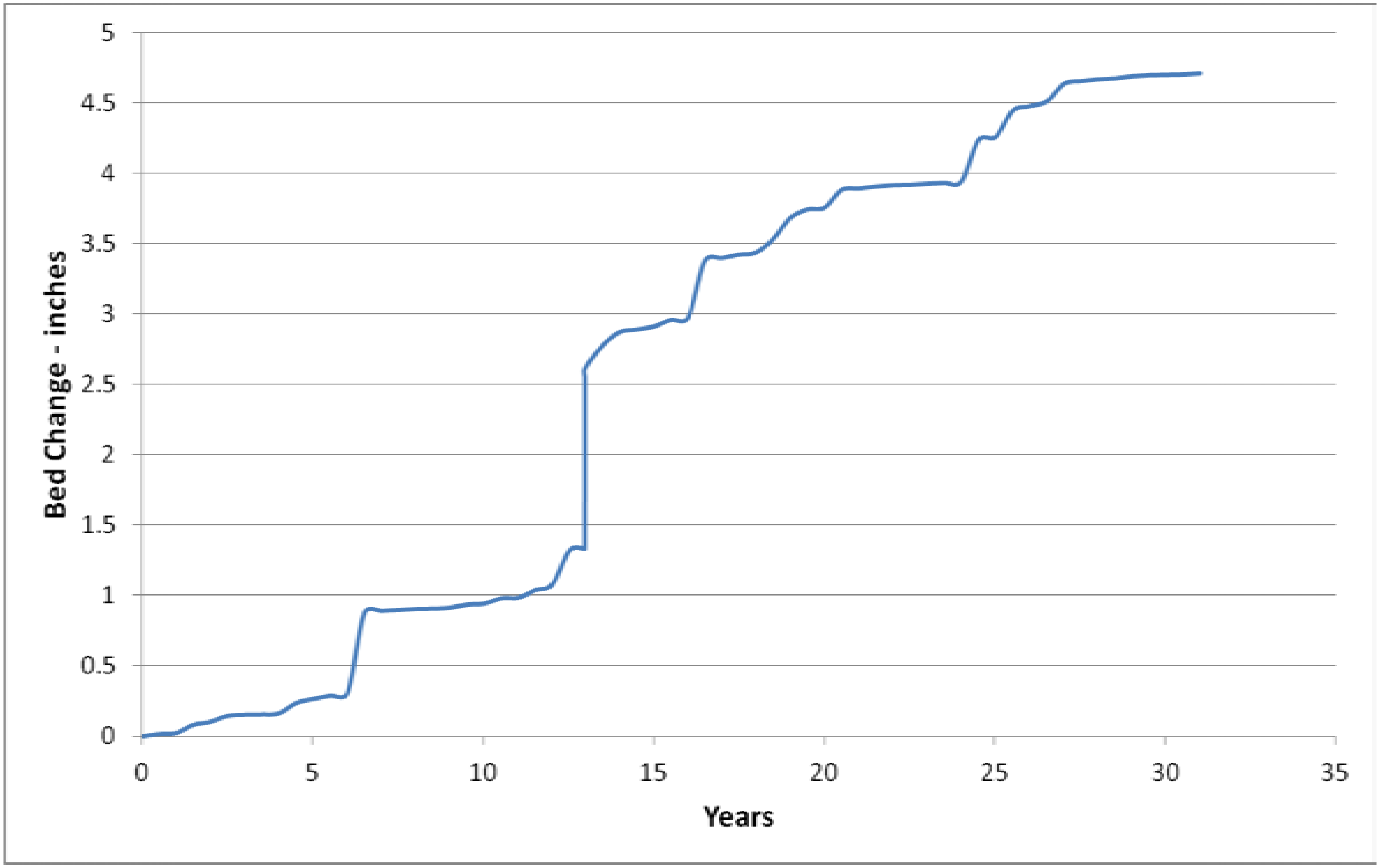

Figure 24. Bed change over the thirty year record for P8

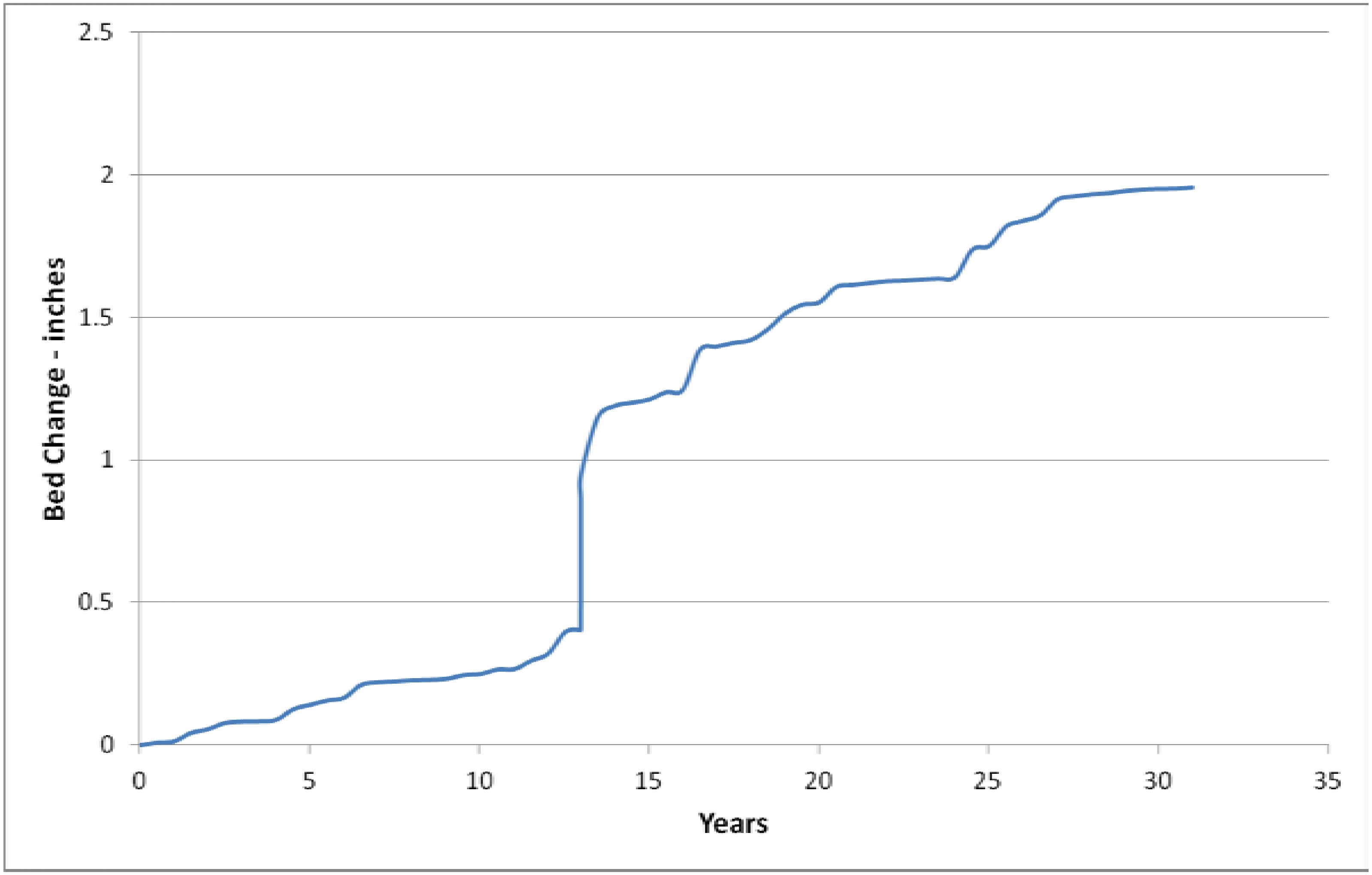

Figure 25. Bed change over the thirty year record for P9

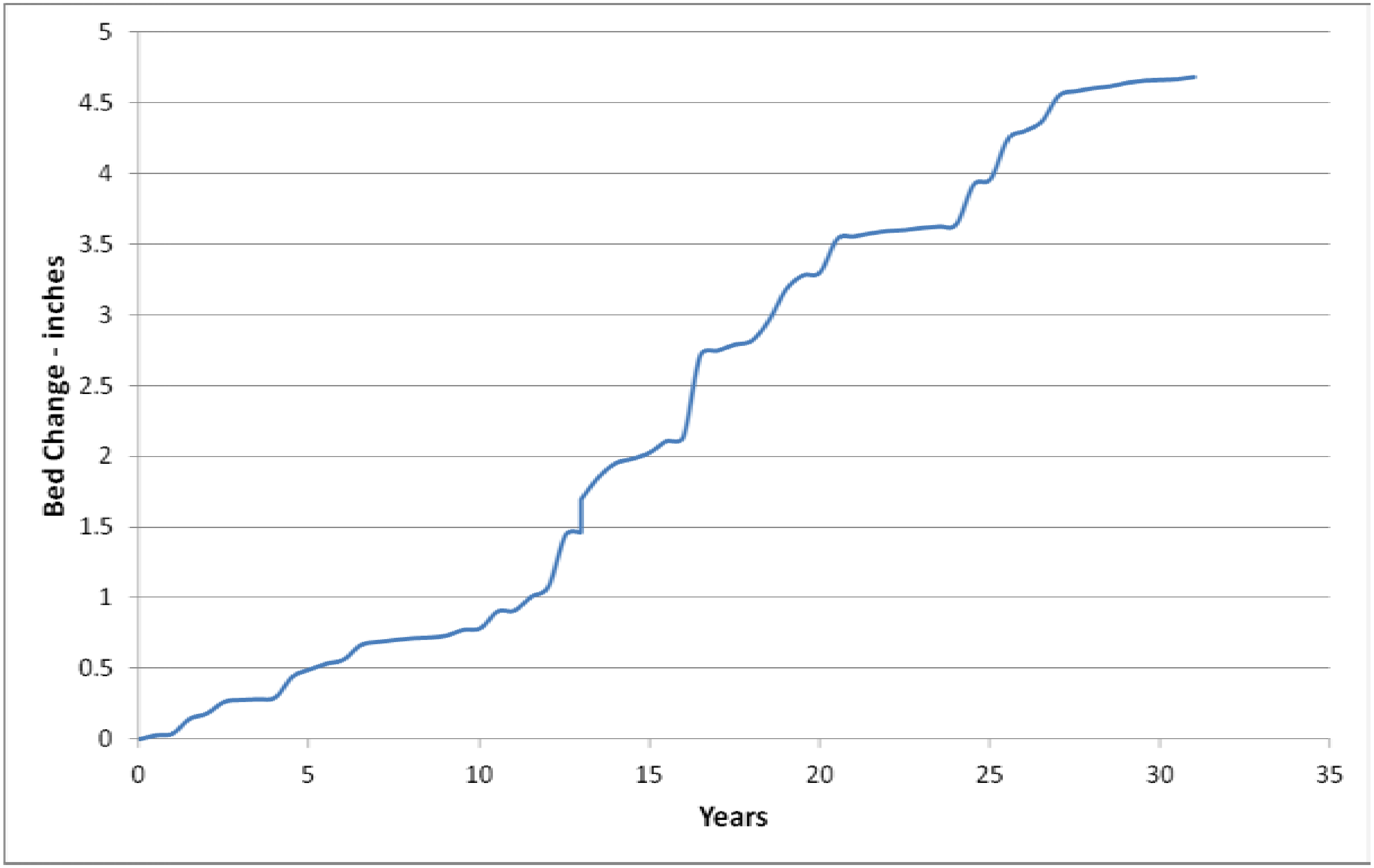

Figure 26. Bed change over the thirty year record for P10

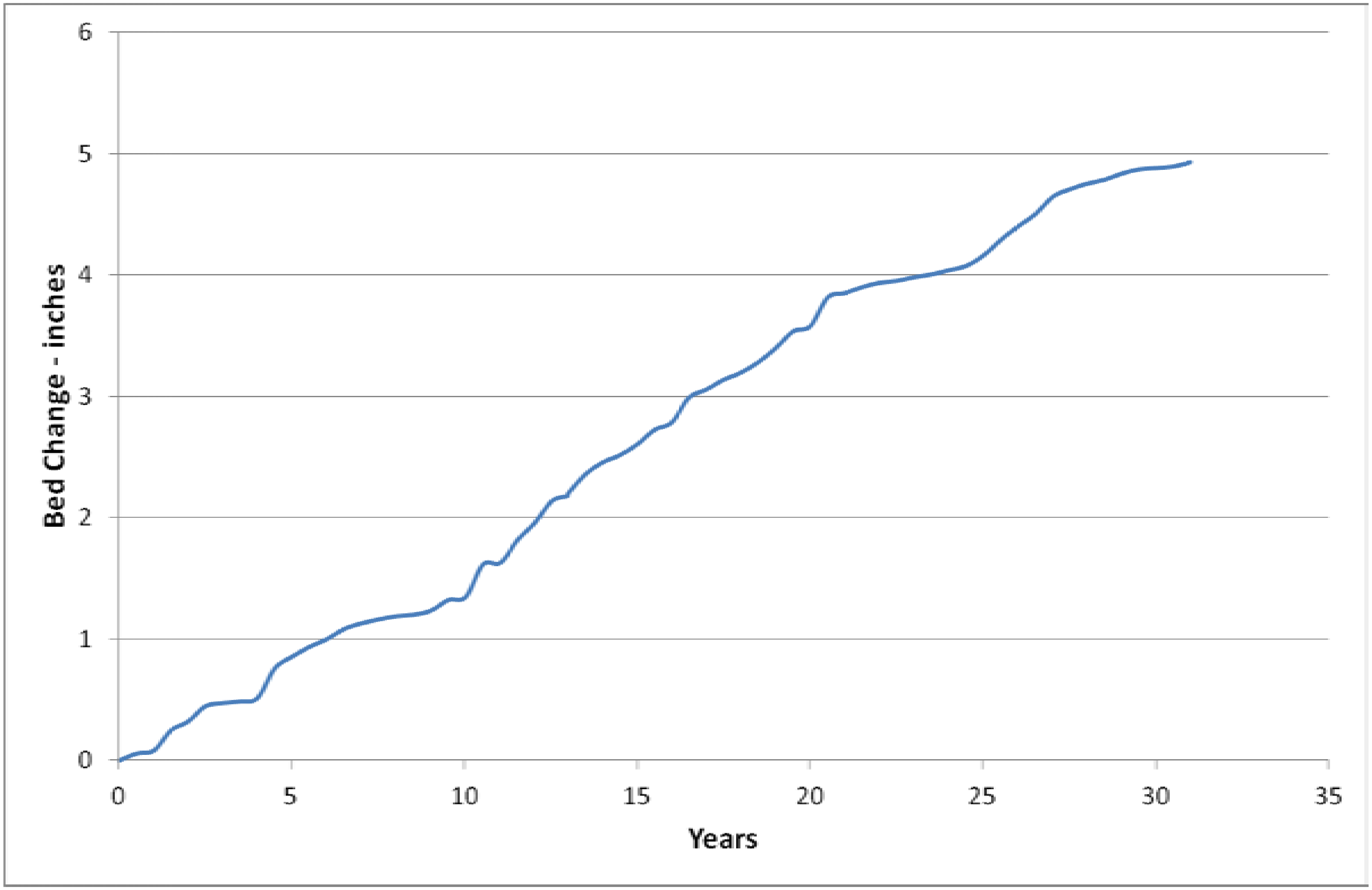

Figure 27. Bed change over the thirty year record for P11

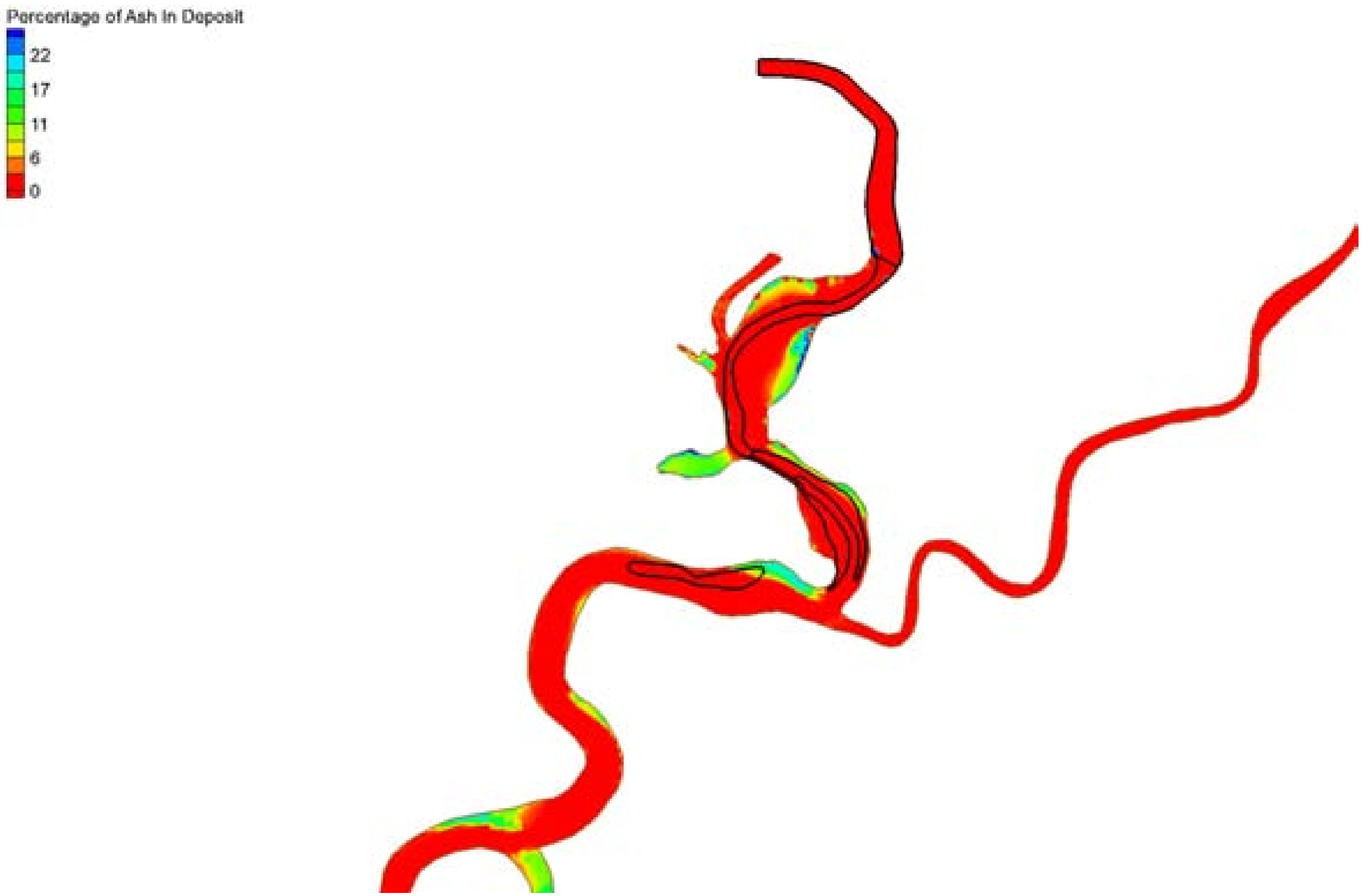

Figure 28. Percent of ash in sediment deposits after fourteen years

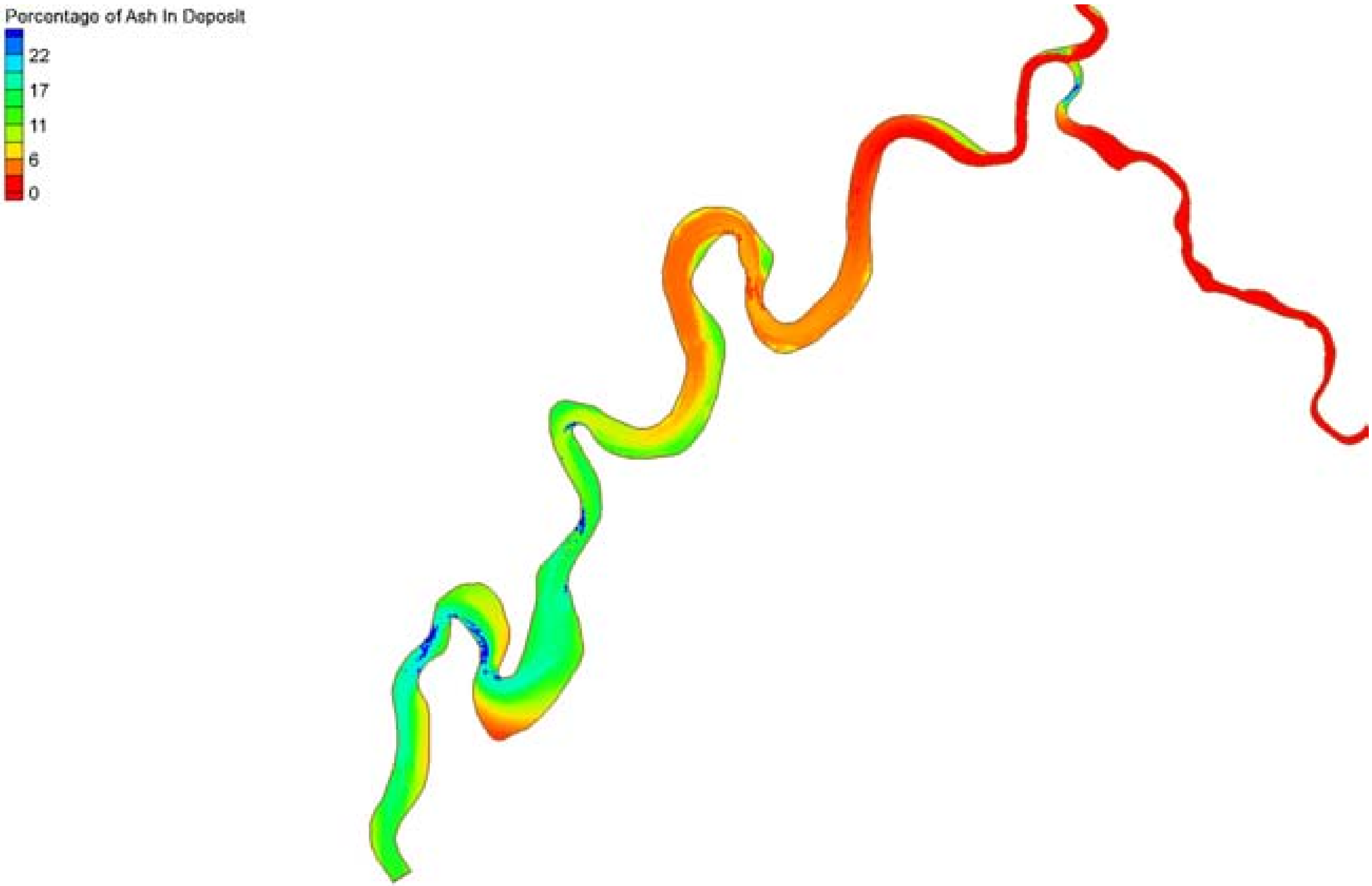

Figure 29. Percent of ash in sediment deposits after fourteen years – lower Watts Bar Reservoir

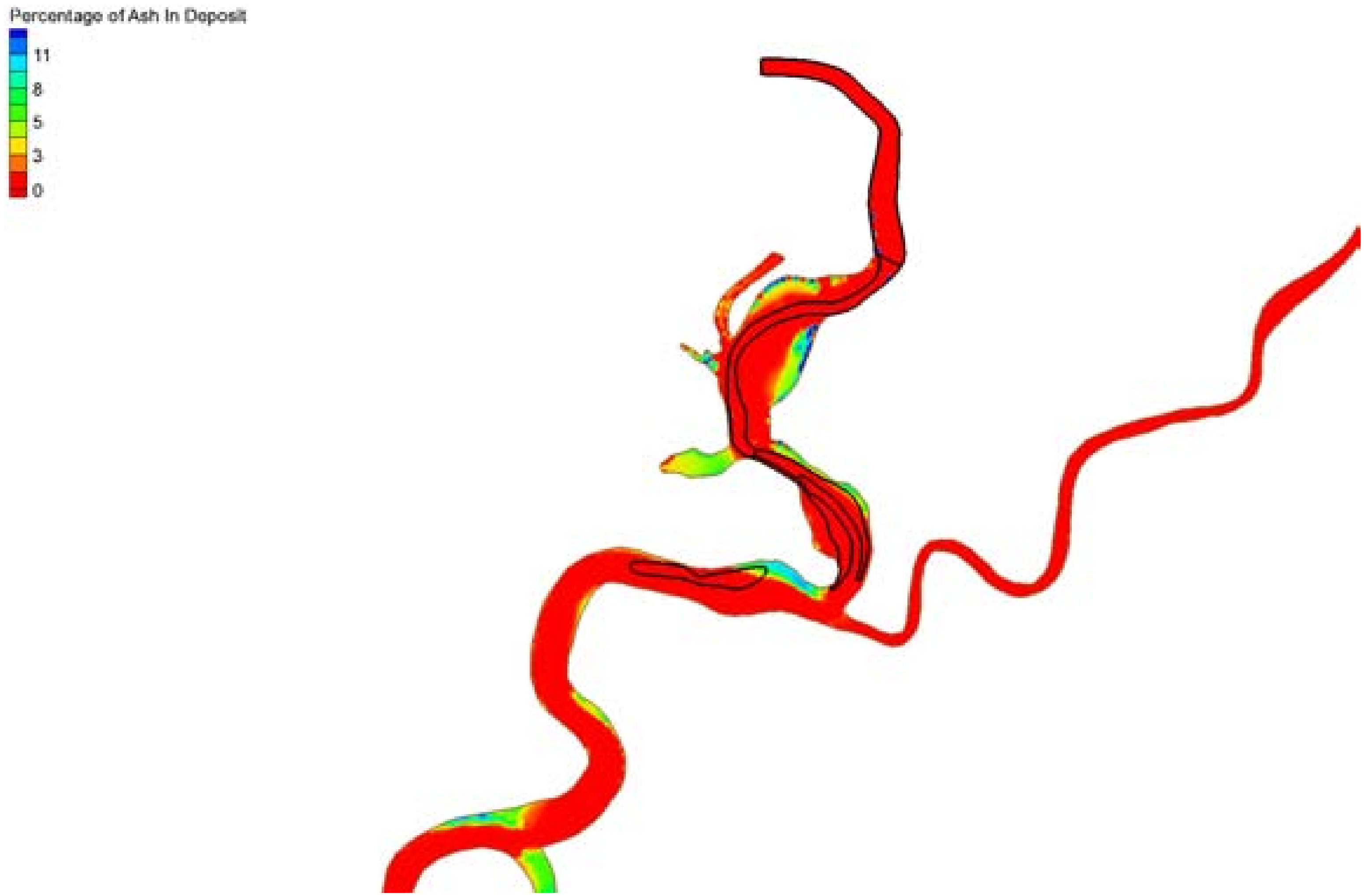

Figure 30. Percent of ash in sediment deposits after thirty years

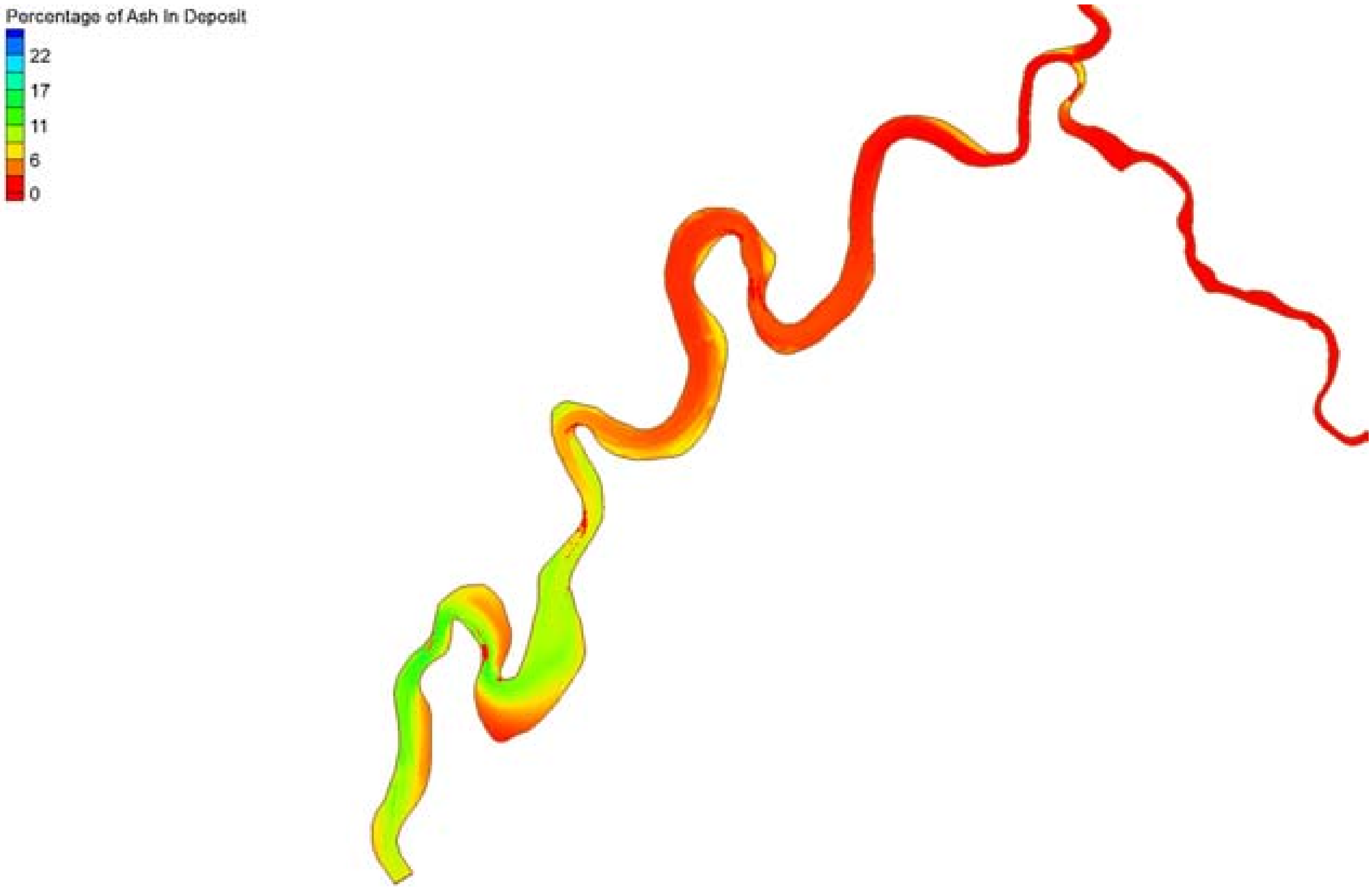

Figure 31. Percent of ash in sediment deposits after thirty years – lower Watts Bar Reservoir

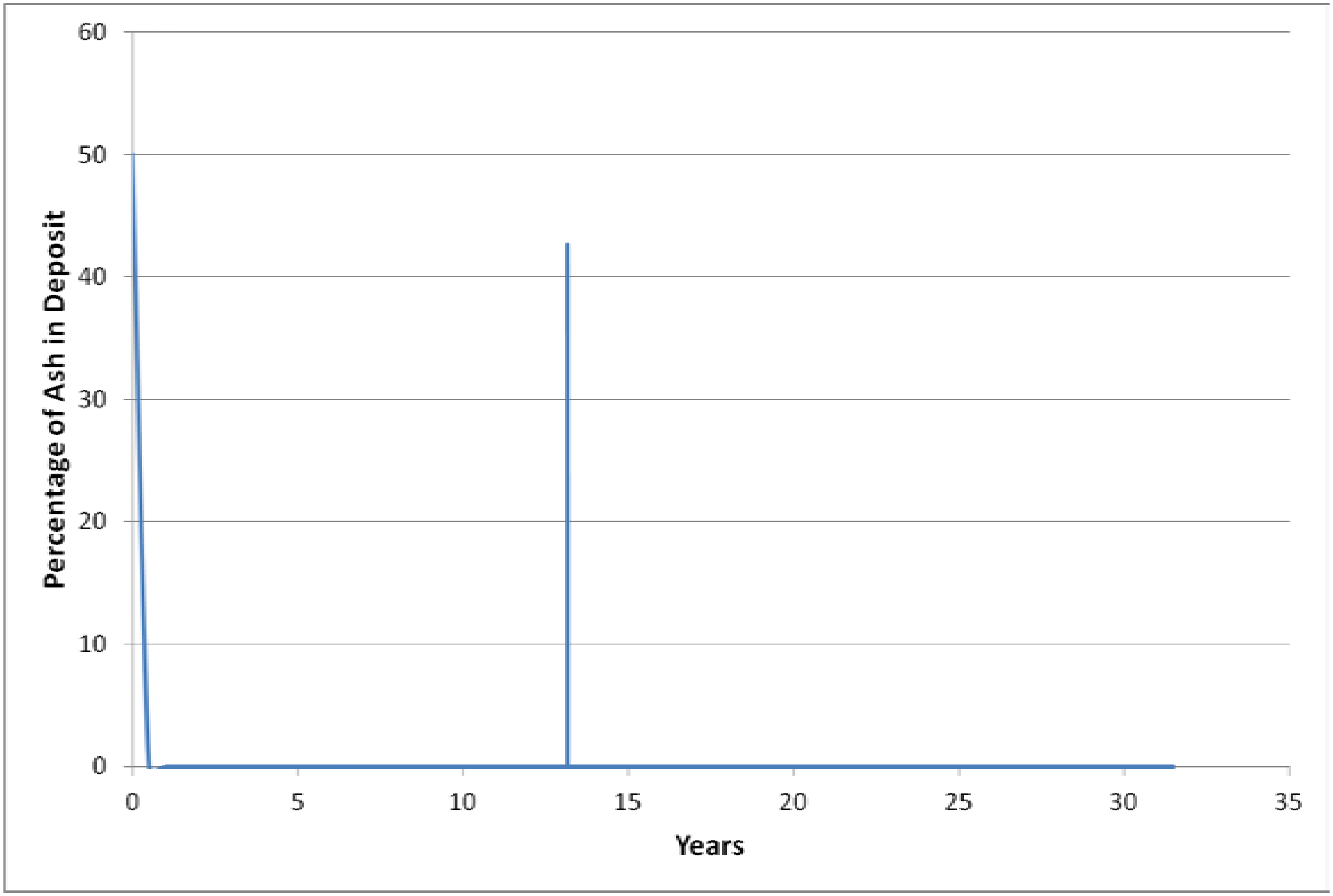

Figure 32. Percentage of ash at P1 over time

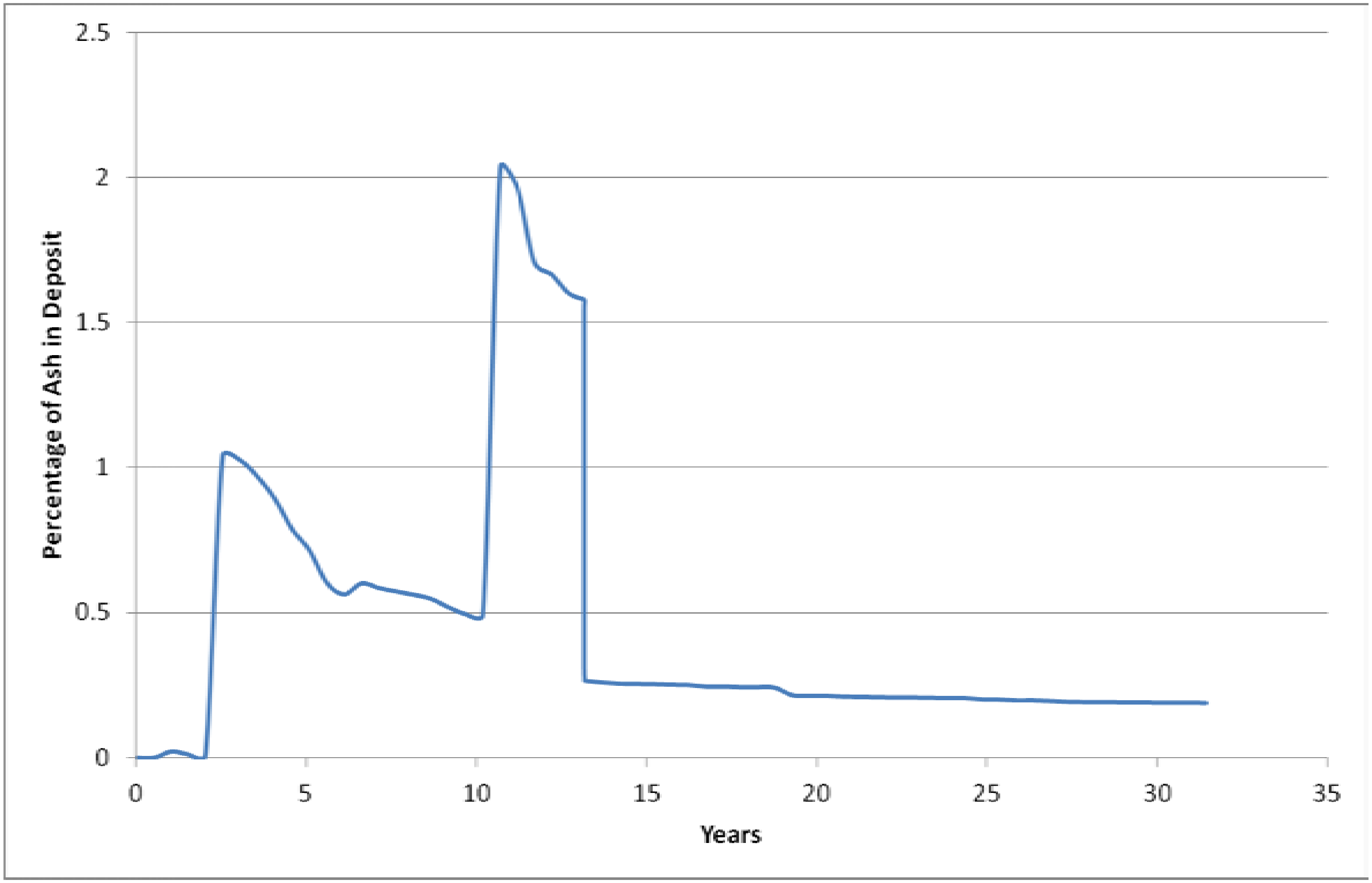

Figure 33. Percentage of ash at P4 over time

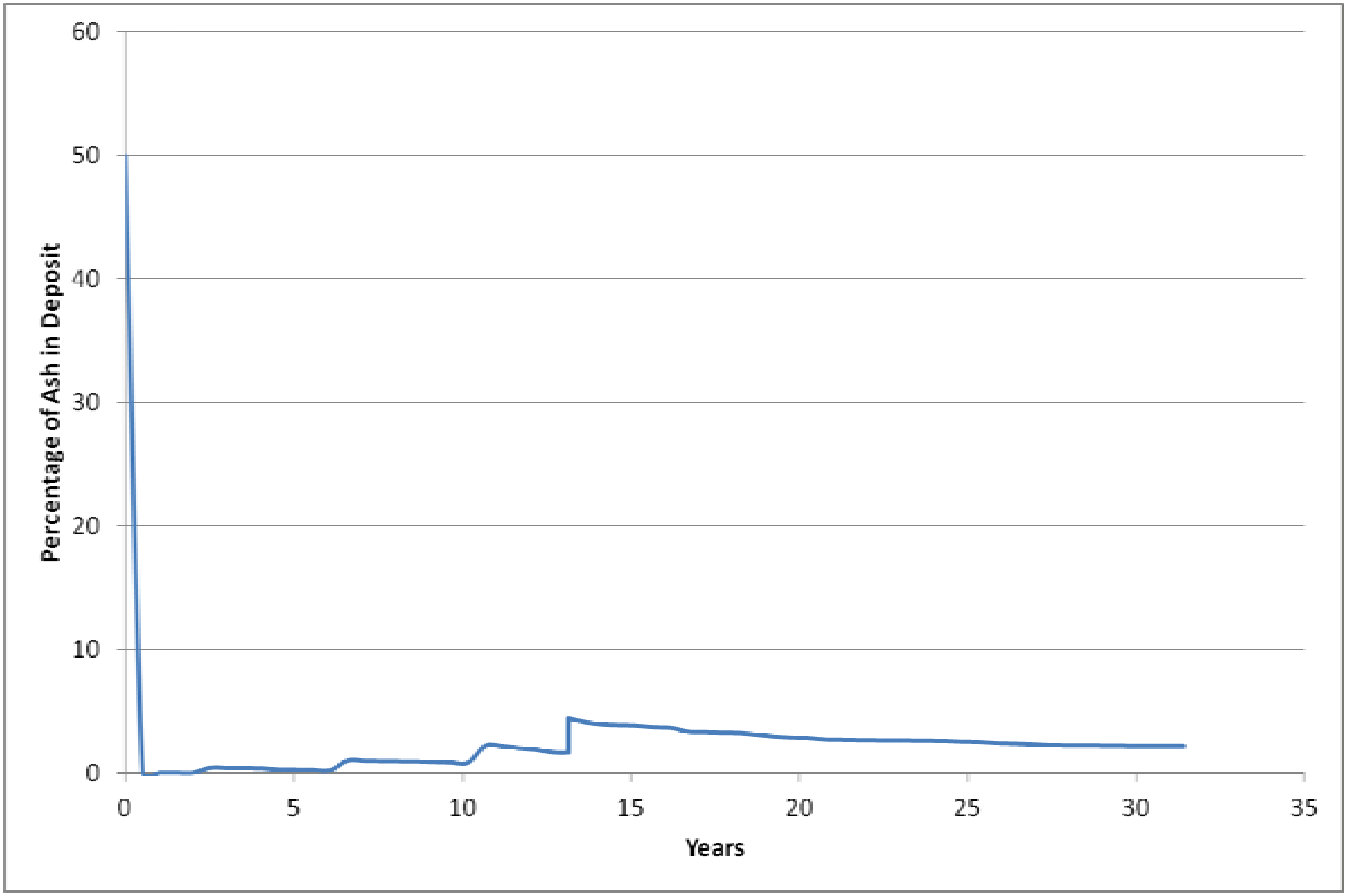

Figure 34. Percentage of ash at P6 over time

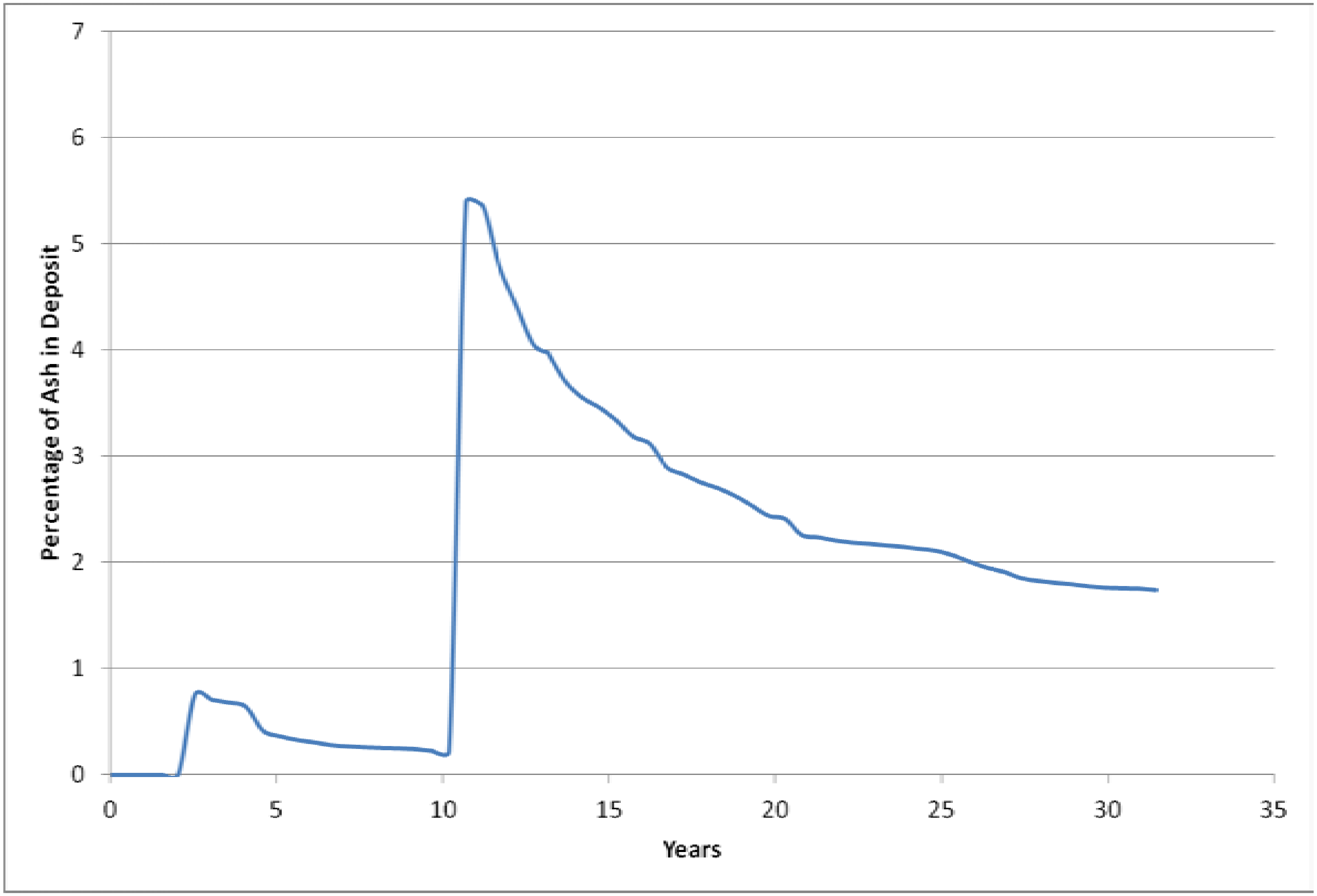

Figure 35. Percentage of ash at P8 over time

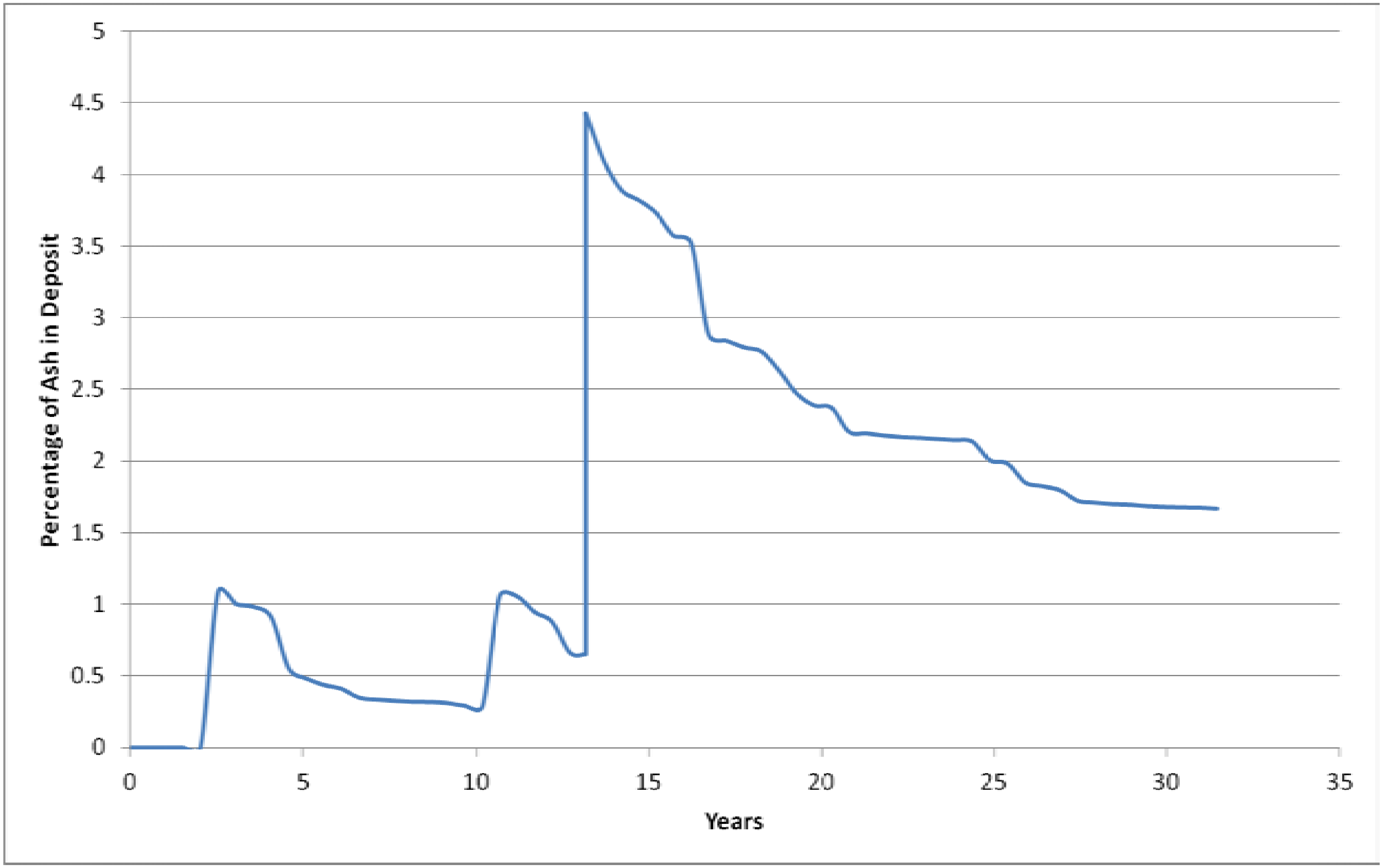

Figure 36. Percentage of ash at P9 over time

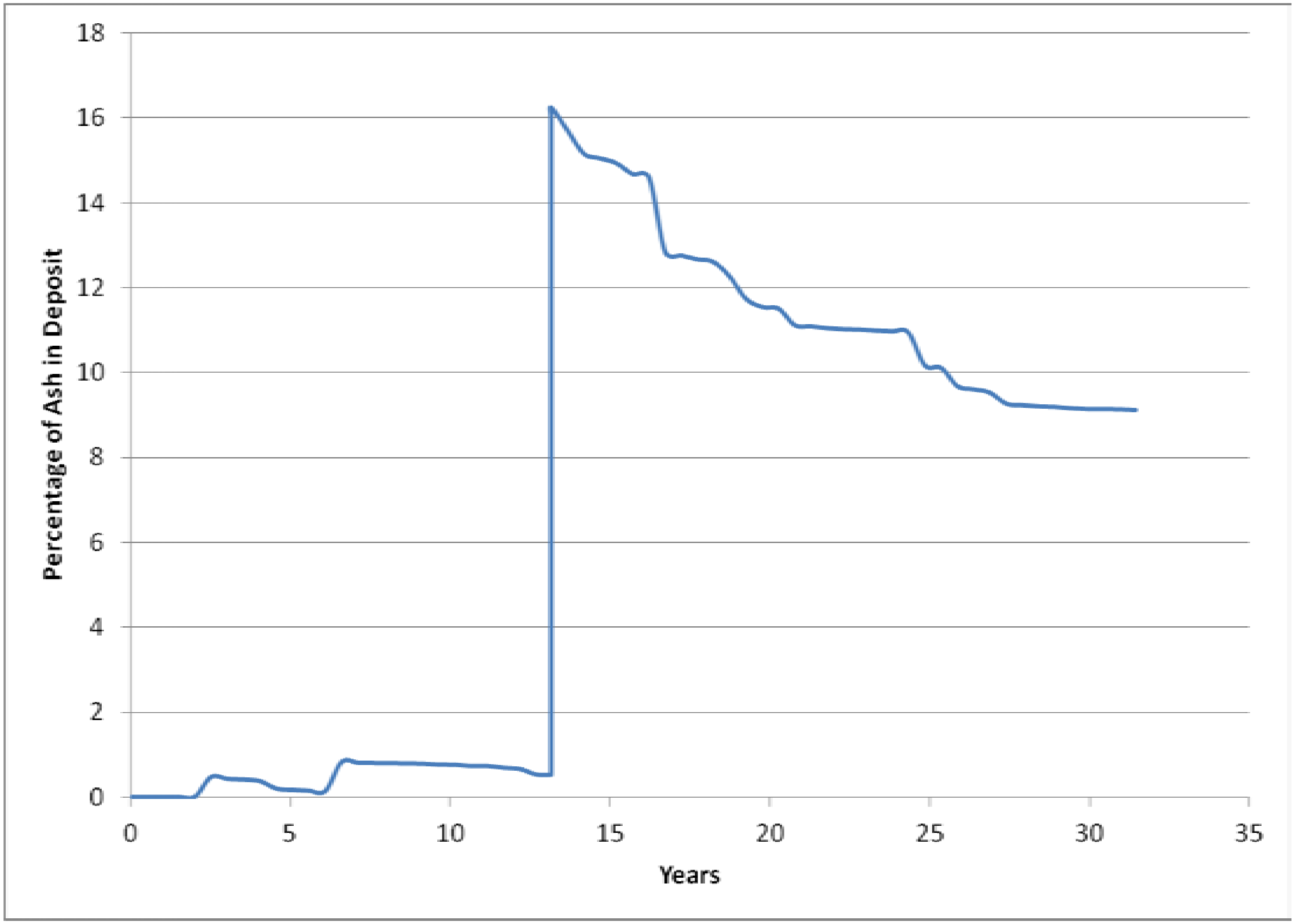

Figure 37. Percentage of ash at P10 over time

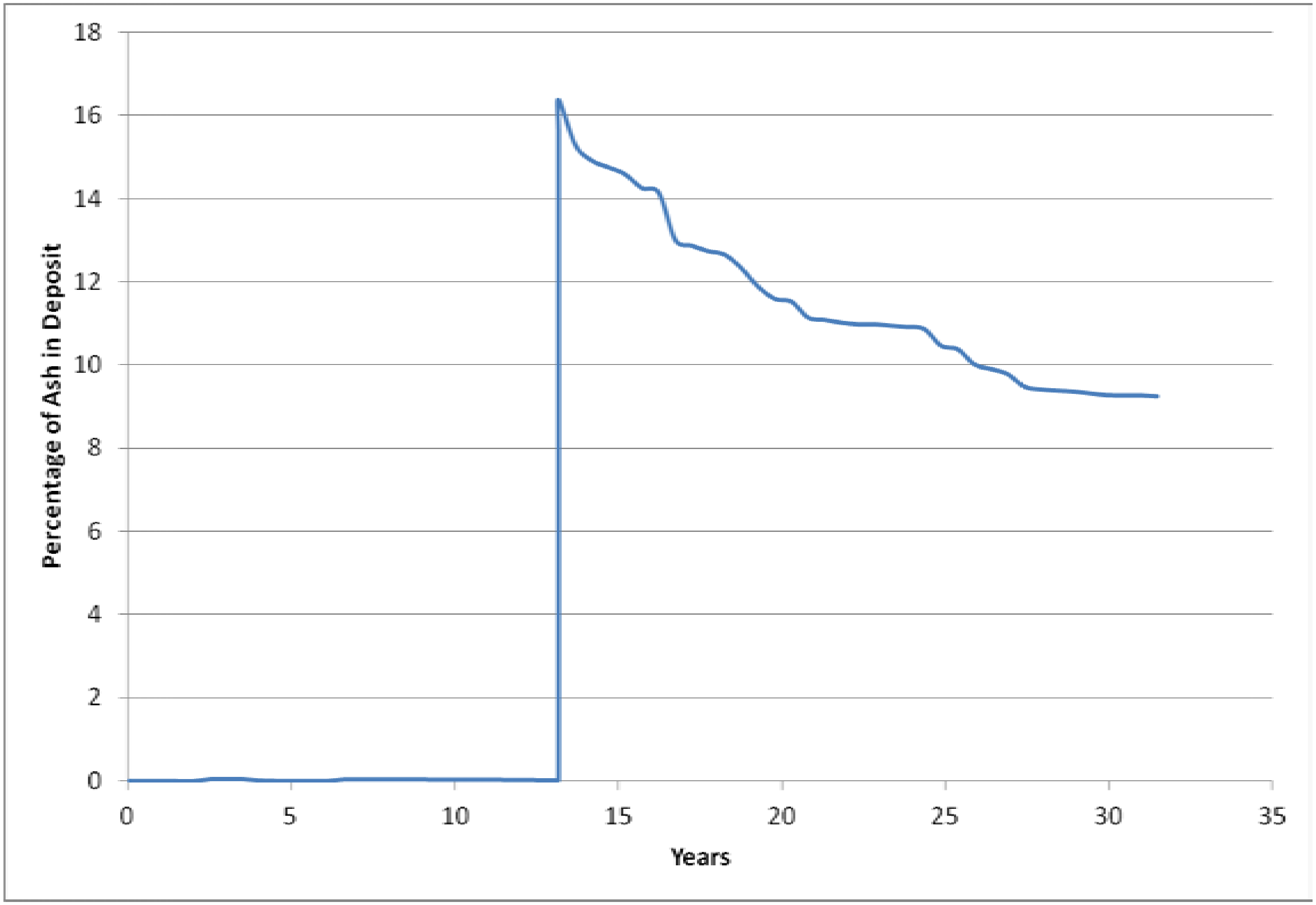

Figure 38. Percentage of ash at P11 over time